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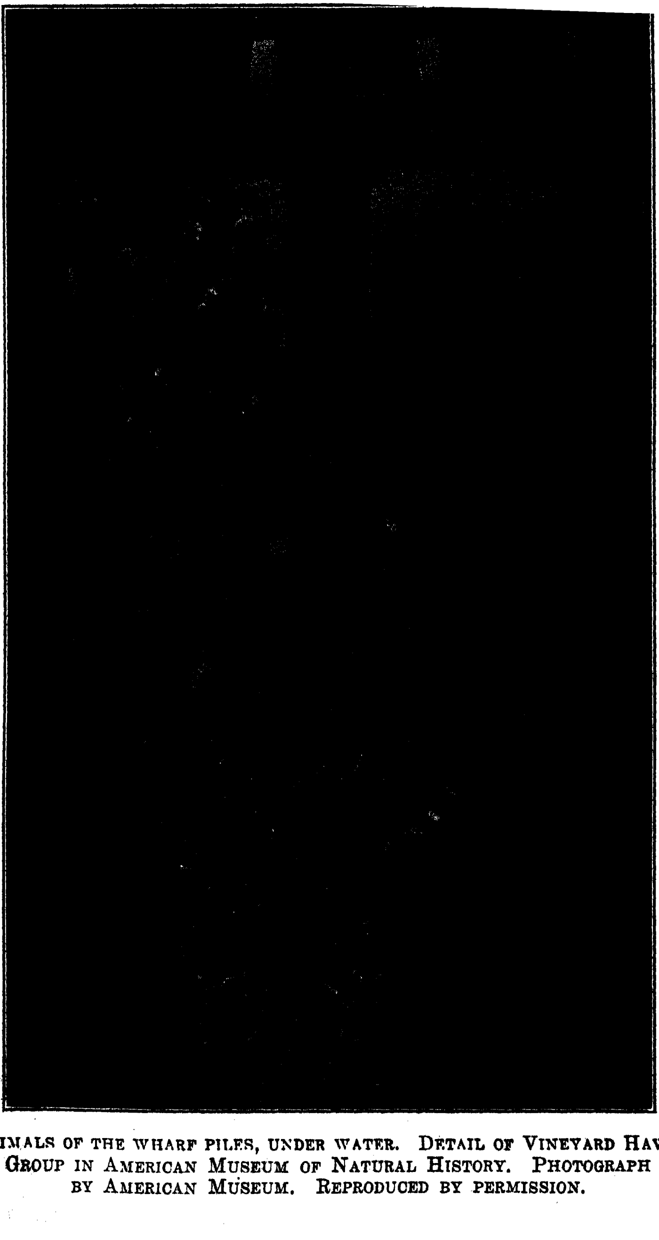
A TEXTBOOK OF GENERAL BIOLOGY



ANIMALS OF THE WHARF PILES, UNDER WATER. DETAIL OF VINEYARD HAVEN GROUP IN AMERICAN MUSEUM OF NATURAL HISTORY. PHOTOGRAPH BY AMERICAN MUSEUM. REPRODUCED BY PERMISSION.

A TEXTBOOK

OF

GENERAL BIOLOGY

BY

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WITH 334 ILLUSTRATIONS

Third Revised Edition

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PREFACE TO THIRD EDITION

This edition has been prepared in order to bring the text up to date, and to conform with the increasing emphasis on the chemical aspects of biology. The section on plant functions has been rewritten to incorporate the recent research radioisotopes, which has unsettled the conventional attitude toward photosynthesis.

Extensive changes have been made in Part II. The chapter on Some Problems of Biophysics and Biochemistry has been reorganized to simplify and correlate the material, and to include an explanation of radioisotopes. A part of the material has been incorporated in a new chapter, Some Problems of Metabolism. All types of oxidation are explained in some detail, and a new section on organic activators includes discussions of enzymes, vitamins and hormones. More ambitious students may find enlightenment in these chapters which will answer questions roused by discussions of Part I. It is not intended that all students will be required to cope with the advanced material introduced.

There has been rearrangement and modernization of the material in several other chapters of Part II, and throughout the book there have been changes where necessary to bring material up to date. There has been some change in terminology in keeping with modern trends, and the new method of calculating geologic time is included. Attention has been given to all requests and criticisms, and it is hoped that this edition will meet with the approval of those who use the text.

CHAMBERSBURG, PA. E. GRACE WHITE.

PREFACE TO SECOND EDITION

In preparing this revision, I have attempted to meet the suggestions made by teachers now using the text. This has involved mainly the strengthening of the botanical section, some rearrangement, and the addition of a considerable amount of material.

In the botanical section the root has been given equal treatment with the stem. The origin of the stele has been described and a discussion of plant adaptation has been added. In this connection I have had the assistance of suggestions and criticisms from Dr. Raymond J. Poole, Professor of Botany at the University of Nebraska, and from Dr. John A. Yarbrough, Assistant Professor of Botany at Baylor University in Waco, Texas, and I wish to express to them my appreciation of their kindness in pointing out possible improvements.

The section on the Problems of Biology has been made Part II of the revision instead of Part III, thus permitting the use of the progressive series of plant and animal types as a separate course if desired. In this section scattered references to biologic history have been united into a chapter entitled "Some Problems of the Past," and the chapters formerly devoted to metabolism and protoplasm have been rearranged and revised by Dr. J. F. McClendon, Professor of Biochemistry at the University of Minnesota, under the heading "Some Problems of Biophysics and Biochemistry." Dr. McClendon has brought to this chapter the touch of the specialist and has added several subjects of timely interest. It is with the greatest appreciation that I make this recognition of his assistance.

Several new types have been added to both the plant and animal series, and the subjects in general have been brought up to date.

Fifty-three new illustrations have been added, the majority of which are original. I am indebted for photographic material to Dr. John K. Small of the New York Botanical Gardens who has kindly placed his collections at my disposal and interested others in doing likewise. I am also indebted to W. M. Porterfield of the Botanical Gardens, to Dr. David Kribs of the Pennsylvania State Forest at Mount Alto, and to Mr. Robert Benson Gordon of the University of Ohio for photographs of special interest, and to the Wild Flower Preservation Society of Washington, D. C., for several invaluable photographs.

I wish also to express my appreciation to my colleagues and students at Wilson College, whose suggestions and assistance have added materially in the preparation of this revision.

E. GRACE WHITE.

CHAMBERSBURG, PA.

PREFACE TO FIRST EDITION

This book is the outgrowth of the course given at Wilson College during the past ten years. It is written with the conviction that a textbook should do more than repeat the work of the classroom. It should contain material to clarify and amplify discussion; it should provide sufficient descriptive detail for reference and comparison; and it should give the beginning student glimpses of many possible fields for future specialization.

It has been my experience that the student comes more quickly to an understanding of life as an organic whole by first observing known types of life, which can easily be compared with one's own experience, than by a study of the cell which is a comparatively unknown field. Moreover, the work of the first few weeks leaves a less deep impression for detail than work done after a background has been established. For that reason a type has been chosen for the initial work which is easily obtained, easily observed in its natural state, and yet is of little phylogenetic importance, leaving the all-important vertebrate to its logical place in the phylogenetic series.

Throughout the book structure has been handled apart from function. In the course as presented by the author the physiologic material is discussed in the classroom, and the morphologic material is handled in the laboratory, the book serving as a laboratory guide. Work with the microscope is constantly interspersed with the handling of larger specimens. The beginning student is easily thrilled and easily tired by microscopic work, and interest is more readily maintained if this type of work is not too continuous. For this reason the material on the cell has been interpolated between the material on the typical animal and that on the typical plant. This arrangement also serves to introduce the student to cell structure before studying the cellular structure of plant stems.

The book is arranged in three parts, but the material in Part III can be divided and interspersed at any point without disturbing the sequence. The first part treats of life as a whole; a typical animal, a typical plant; typical one-celled life and bacterial life completing a cycle of interdependence. Questions of action and interaction, organization, variation, life, death, and reproduction are introduced.

Part II treats with equal completeness of the animal and plant kingdoms, the morphology and life history of each form being included. No one course can possibly treat of all the types presented, but the instructor is given ample choice, and the student has material for constant comparison. The treatment of both series under progressive types of organization provides a logical outline, a skeletal framework, so to speak, on which the student may build a picture of progressive development.

Few texts treat of both series equally, and it is hoped that this book may fill a real need in the educational world. It may serve equally well as a general text by the omission of specialized types, or as a text for a specialized course by emphasis on the phylogenetic series.

Part III takes up the problems of modern biology and touches on many subjects. There is ample material for discussion and for additional reading.

A glossary of terms found in the text is included. The student should consult this glossary constantly.

The book has been in use in mimeographed form for several years, and has had the advantages of criticism and improvement from practical use. I wish to express at this time my appreciation to those whose helpful suggestions have made the rendering of this edition possible. I wish especially to thank Dr. Robert Chambers for suggestions covering the field of zoology, and Dr. Laetitia Snow and Dr. Louise Sawyer for suggestions covering the botanical section. Others who have given helpful suggestions are Dr. William K. Gregory, Dr. Gary N. Calkins, Dr. Edwin G. Conklin, and Professor Ulric Dahlgren.

I also wish to thank Dr. Elizabeth Hartman and Miss Elizabeth Drumtra for their invaluable aid in assembling the illustrations, some of which are the work of Wilson College students and alumnae. Special mention is due Mrs. Eleanor

Sloan Hough (1927), Miss Elizabeth Drumtra (1928), and Miss Anne P. Young (1931) for original contributions of exceptional merit; and Miss Florence A. Basehoar (1932) for several careful and detailed studies of plant cells.

The botanical material was gathered locally except for the *Marchantia domingensis*. This species was contributed by the Department of Botany at the University of Nebraska where it has been recently described. The details have been worked out by Miss Muriel Hooper (1932) under the direction of Dr. Hartman.

I am indebted for the use of photographs to the American Museum of Natural History in New York City; to the New York State Museum; to Mr. H. R. Bezant of Florida; to Mr. A. E. Galigher of California; to the General Biological Supply House in Chicago, and to many authors and publishers for permission to reproduce or modify their work.

E. GRACE WHITE.

CHAMBERSBURG, PA.

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A TEXTBOOK OF GENERAL BIOLOGY

GENERAL BIOLOGY

PART I

THE UNITY OF LIFE

CHAPTER I

INTRODUCTION

Biology is the science of life. Science means knowledge (Latin, *scientia*), and the Greek synonym, λόγος, is used in combination with βίος (life) to form the word "biology." It is concerned with all things that live; with their structures, their functions and their activities, physical, chemical, and psychological. It is concerned with their most minute parts and their most comprehensive relationships, with their present usefulness and their past history. It is the most comprehensive of all modern sciences. Built on the foundation of the exact sciences, physics, chemistry, and mathematics, it reaches out into the applied sciences of psychology and sociology. It touches on philosophy and builds on geology. There is scarcely a phase of human endeavor that is not to some extent influenced by biological thought.

It is small wonder then that the general biology course admits of many lines of approach. It must first of all lay the foundation for future work in more specialized fields, but it should also aim in a general way to satisfy the inherent curiosity about life and to arouse a wide interest and a comprehensive view.

It is the aim of this course to accomplish these ends by so unifying the problems of life through a survey of the interactions and interrelations of living organisms, that the details may gain significance in the light of a coherent whole.

Scope of Biology

The day is past when one can hope to grasp all that biology has to offer and specialization into more and more narrow fields has become essential in order that progress may go on. There is the danger of too great specialization, of course, as of too widespread interests. It is almost as useless to know too much about too little as too little about too much.

The general subject can be approached through a study of botany, dealing specifically with plant life, or zoology, dealing with animal life, but neither is a complete science in itself, so intimately are the forms of life related. The more general fields of biology apply equally to both. Morphology, the study of form; physiology, of function; and embryology, of development, are methods of approach which are interdependent. Genetics is an experimental field dealing with the laws of heredity; ecology, a fairly new development in which the organism is studied in relation to the environment; and taxonomy, a more specialized branch dealing with the classification of animals and plants.

It is possible to delve deeper into any one of these fields. Study of gross internal structure is anatomy; of the microscopic detail of tissues, histology; of cellular structure, cytology. When the biologists reach the contents of the cell they meet the other sciences and must pursue physical biology, and biochemistry.

There are specialists who find a life work in studying the mysteries of bacteria, bacteriology; of the unicellular animals, protozoology; of the insects, entomology; of the fishes, ichthyology; of the reptiles, herpetology; or of the birds, ornithology.

There are problems of race development to be reached through the study of ancient life, palaeontology; of ancient man, anthropology; and of animal distribution, past and present, zoogeography. Plant geography covers the distribution of plants in a similar way.

In medicine, which is one phase of applied biology, there are special fields of practice, such as children's diseases, pediatrics; mental disorders, psychiatry; etc., and all the problems of nutrition and dietetics which deal with foods in health and in disease; as well as the great field for work in the prevention of disease, serum therapy, immunology, parasitology, and epidemiology.

Other applied phases of biology are agriculture, with its far-reaching economic interest; and eugenics, the application of the laws of genetics to the human race with a hope for social control and race betterment.

The Subject

It is easier to say what life is not than to arrive at any adequate definition of what it is. A thing is either alive or it is not alive, and the distinction between the living and the dead is the sharpest and most intangible one in nature. Much that we know about life has been gleaned from a study of the dead, for the components of the substance which lives, protoplasm, are the same dead or living; yet the dead is just as lifeless as that which has never been alive, and there are compounds which simulate very closely the functions of the living without being in any sense alive.

It is not always possible to recognize life. The dried seed on the closet shelf, the spores floating in the air, the frog hibernating in the ground; these bear no semblance to life, yet, not one of them but will return to an active state when submitted to sufficient warmth and moisture. The test of life, therefore, is not in the activities but in the power to be active and to retain activity through self-repair. It goes still further and involves both self-preservation and race-preservation through the functions of growth and reproduction.

It is not possible to point to any one thing as a criterion of this power. Motion is a form of energy released in the organism when food is burned, or oxidized. An automobile or an aeroplane will move as efficiently when gasoline is burned. So this is a corollary, not a criterion of the growth phenomenon.

Growth itself is not an unfailing symbol of self-repair. There are crystals which grow by accretion of particles and even bud off new crystals. To be sure, living things add new particles internally by a chemical process known as intussusception, but there are nonliving colloids which grow by intussusception, and even divide when they have reached a certain size, an analogy to self-repair and reproduction, with no faintest relation to life.

It is, therefore, in the constant adjustment of the organism to an ever changing world; a series of interactions between the internal and external environment that the organism stands on a plane apart. In every conceivable type of environment from boiling water to ice; from the arid desert to the luxuriant swamp; from the heights of the air to the depths of the sea, we find life; and so variously modified to meet these conditions that a change of the environment often means death.

In the activities of living organisms which are the expression of self-preservation and race-preservation we find a startling similarity and interdependence throughout the world. It is only in adaptation that we find variety and progressive organization, and these very adaptations express the interrelations which make life a complex, though coherent whole—not to be understood through any single form. In attempting a study of life, therefore, we must first attack life as a whole through the activities of animals and plants, and thus arrive at an understanding of life as a self-preserving and race-preserving system, accomplished through a constant interaction between the internal and external environment.

CHAPTER II

THE GRASSHOPPER

The grasshopper has been chosen as a type upon which to base an introduction to animal life because it fulfills all the requirements of a living animal with organs and systems large enough to be seen, and yet is not a type of great importance to the study of comparative forms. The initial examination made by the elementary student should not be so detailed as to detract from the picture of the whole, and the introduction at this point of an important type species, such as the frog or the earthworm, would place the emphasis on detail of structure. Moreover, the grasshopper is a widely distributed form, some species being available on practically every college campus. This makes it possible to obtain living animals for comparison with the preserved laboratory specimens, thus completing the picture of the organism and facilitating the correlation of structure with function.

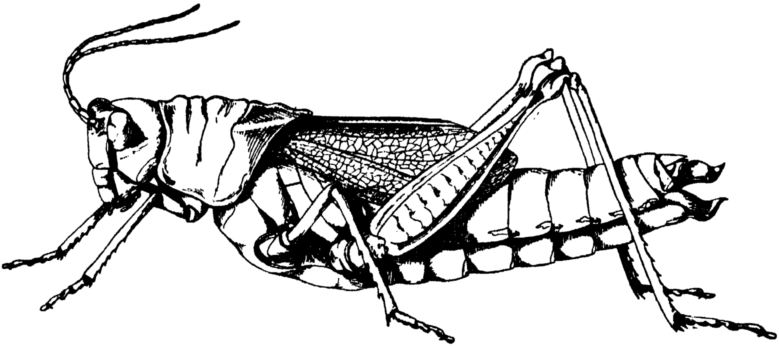

Fig. 1.—*Rhomaelia microptera* (life size). (Original drawing by Eleanor Sloan Hough.)

The description which follows is based on the large Florida lubber grasshopper, *Rhomaelia microptera,* since these are now available at the supply houses in excellent state of preservation.

ORGANIZATION

"Study Nature, not books" was the maxim of Agassiz, the great teacher. In the grasshopper we have a bit of nature, and observation of the living specimen will reveal certain facts, which, while apparently obvious, are yet of utmost importance.

Looking directly into the face of the grasshopper, one observes that both sides are alike. An eye on one side, an eye on the other; and, farther back, a leg on one side, its exact duplicate on the other. So, from head to tail, the grasshopper is built on the plan of *bilateral symmetry.*

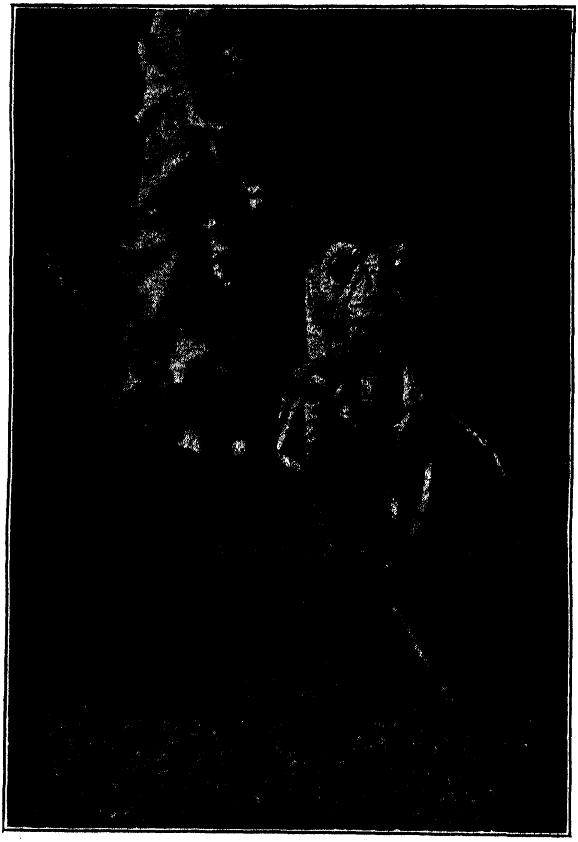

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Fig. 2.—Grasshopper. Shed skin mounted and photographed. Illustrates bilateral symmetry. (Copyright H. R. Bezant. Reproduced by permission.)

If observed from the side, the regions of the body will be apparent: a *head* in front; then the *thorax,* bearing the legs and wings; and finally the long, segmented *abdomen.* Note that the regions of greater activity are in advance, the head with the sensitive organs in the lead. Thus we find a *marked antero-posterior differentiation.*

There is yet another differentiation between the top and bottom of the grasshopper. The skeletal material which covers the back and sides is separate from the piece underneath, to which it is joined by a membrane. For convenience, the term, *dorsal,* is applied to the back, and *ventral* to the bottom because by these terms corresponding regions of other animals can be similarly referred to, whether the dorsal side be on the top or the back of the animal. Because of the ventral location of the nervous system in the grasshopper in contrast to its dorsal position in all vertebrates the differentiation here represented is called *ventrodorsal,* the nervous system marking the more active region as in the case of the head.

This is the general plan of organization in the grasshopper; the plan on which all bilateral animals are built. The organs found in the midline will be unpaired or fused, and all organs to the side of the midline will be paired, the organ on the right being the mirror image of the organ on the left.

EXTERNAL STRUCTURE

The Cuticle

The entire body of the grasshopper is covered by a horny substance, the *cuticle,* which is a lifeless layer laid down by the cells of the *epidermis* underneath. The epidermis is the true skin; the cuticle is a *secretion,* manufactured by the cells, called *chitin* because of its horny nature. It constitutes the *exoskeleton* of the animal and is the part shed during growth.

The cuticle is divided into plates, called *sclerites.* Those on the dorsal side are *tergites,* those on the ventral side are *sternites,* and the lateral ones are the *pleura.* Sclerites are joined together by *arthropodial membranes* which are sometimes reduced to mere sutures, as in the head where the sclerites are fused into a boxlike epicranium.

Segmentation

Segmentation, or metamerism, is a form of organization in which structures are serially repeated. In the grasshopper, segmentation is external only, no partitions crossing the body cavity. The modifications which increase anteriorly, are a mark of the high degree of organization in the grasshopper. Segmentation can be seen most clearly in the abdomen where the sclerites are arranged in serial rings. Typically there are one tergite, two pleura, and one sternite in each segment. The insertion of three pairs of legs marks the position of the somewhat irregular thoracic segments, while in the head all segmentation has been obliterated by the fusion of sclerites. The presence of antennae and paired jaws, the head appendages, give some clue to a segmented origin, however, and the development of the head discloses the fact that six segments are fused in the epicranium.

Organs of the Head

The segmentation of the head is irregular. Sutures mark off a crown, a forehead, and two cheeks (genae). The upper lip, *labrum,* is a movable and bilobed sclerite attached to the forehead by a rectangular sclerite, the *clypeus.* On the underside of the *clypeus* and forming the roof of the mouth is an elevation, the *epipharynx.* It is thought to have a sensory function.

The *compound eyes* are the most conspicuous organs on the head. They are situated on the cheeks and are one third the length of the entire head. Under the lens they disclose an hexagonal construction of radially arranged lenses, the *ommatidia.* Each lens is a crystalline cone, the point of which joins a nerve fiber leading to the optic ganglion. The eye is covered by a thin, transparent cuticle, and each lens is surrounded by black pigment cells.

The *ocelli* are three single eyes, each one a separate lens. There is one anterior and dorsal to each compound eye on the ridge between the forehead and cheek. The third, being unpaired, is central in position, lying in the depression between two ridges in the midline of the forehead.

The *antennae* are the first pair of appendages, set in depressions in the dorsal part of the forehead. They are finely segmented, and are attached to the head by means of a thin

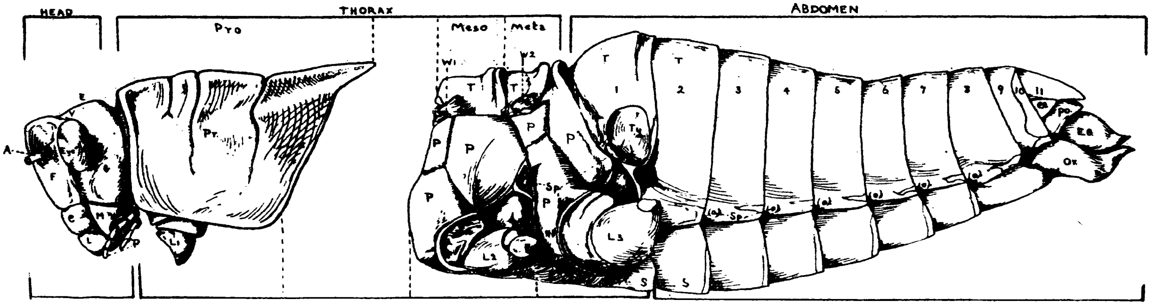

Fig. 3.—External structure of *Rhomaelia microptera* female. The legs, wings, and antennae have been removed, and the head and prothorax are separated from the mesothorax to show the wing attachments. *A*, Antenna; *E*, epicranium; *V*, vertex; *F*, frons; *G*, gena; *C*, clypeus; *L*, labrum; *p*, palps; *m*, mandible; *Pr*, pronotum; *T*, tergite; *P*, pleuron; *S*, sternite; *Sp*, spiracles; *Ty*, tympanic membrane; *L*1-2-3, first second, and third leg attachments; *W*1, attachment of upper wing; *W*2, attachment of under wing; ***1-11*, *segments*** of abdomen; *Ce*, cercus; *Po*, podical plate; *E.G.*, egg guide; *Ov*, ovipositor. (Drawing by Eleanor Sloan Hough.)

membrane which acts as a socket, permitting movement in all directions. They are covered with fine sensory hairs.

The *mandibles* are the second pair of appendages and the first pair of jaws. They are dark in color and very hard, and are toothed on the edge. These jaws work sidewise in eating.

The *first maxillae* are the third appendages and the second pair of jaws. The structure is complex and to be understood only in the light of other appendages of the arthropods. It is outlined here for the purpose of comparison only.

The basal portion is composed of two segments, the cardo below, and the stipes above. From the latter three processes arise the inner toothed lacinia, the oval plate in the middle, the galea, and the outer jointed process of five segments, the *maxillary palps* supported by the palpifer, a small basal joint.

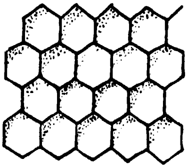

Fig. 4.—*Rhomaelia microptera.* Detail of ommatidia, magnified.

The *labium* is the lower lip, but unlike the labrum, is not a sclerite but the fourth pair of appendages fused. Technically, these are the second maxillae, the third pair of jaws. Like the first maxillae each half is composed of several parts, some of which are only partially fused. The basal portion is the *submentum.* To it is attached the *mentum* from which the labial palps of four segments proceed from a *palpifer.* A pair of flat, movable flaps on the mentum, the *ligula,* form the central portion and function as an under lip. Projecting inward from the midline is the *hypopharynx,* commonly called the tongue because of its supposed sensory function, but actually only the floor of the mouth cavity.

Organs of the Thorax

The thorax contains three segments: the *pro-, meso-,* and *metathorax.* On each segment is inserted one pair of appendages, and on the dorsal surface of the meso- and metathorax there are outgrowths of skin which form the outer and inner pairs of wings.

The cuticle of the thorax is somewhat modified. On the prothorax the tergite is greatly enlarged and is called the *pronotum*. It extends back over the meso- and metathorax like a shield, covering the wing insertions. It is marked by three transverse sutures. The sternite has a large, backwardly directed spine. The pleura are rudimentary. In the membrane between the pro- and mesothorax is a small opening on each

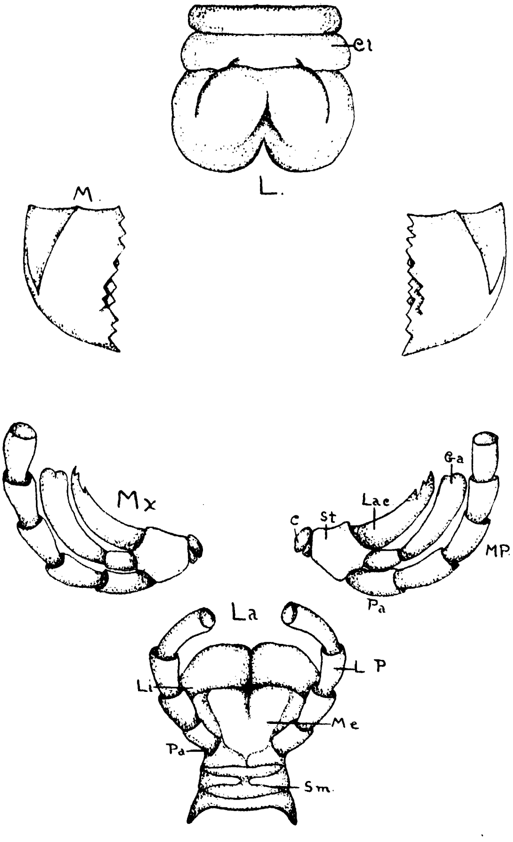

Fig. 5.—Mouth parts of *Rhomaelia microptera*. *L*, Labrum; *M*, mandible; *Mx*, first maxilla; *La*, labium (second maxilla); *Cl*, clypeus; *C*, cardo; *St*, stipes; *Lac*, lacinia; *Ga*, galea; *Mp*, maxillary palp; *Pa*, palpifer; *Me*, mentum; *Sm*, submentum; *L.P.*, labial palp; *Li*, ligula. (Dissection and drawing by Elizabeth Drumtra.)

side called the *spiracle*. There is a pair of these openings on each segment from here to the end of the abdomen.

On the mesothorax, the tergum and pleura are composed of several sclerites, but the sternum is a single broad piece. The sutures separating the meso- from the metathorax are not very clear in the dorsal and ventral region, but between the pleura a suture runs distinctly from the point of attachment of the second leg toward the dorsal tergite. This separates the two segments, and the pleura are again divided by sutures. Posteriorly the metathorax is fused immovably with the first abdominal segment.

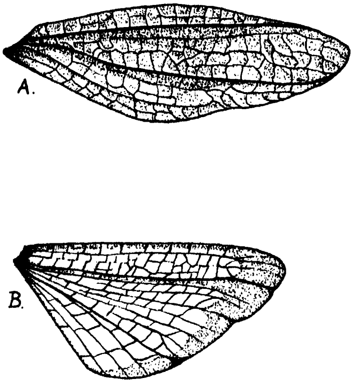

Fig. 6.—*Rhomaelia microptera.* *A*, Upper wing; *B*, under wing.

The *wings* are dorsal saclike outgrowths of the epidermis, the two walls of the sac being pressed together to form a thin membrane. The *veins* of the wing are respiratory tubes filled with air and each surrounded by a tubular blood space, or sinus. In the adult the blood ceases to flow into the wing and it becomes hard and dry. The veins all run parallel to the inner edge of the wing which forms a straight line down the middle of the thorax. It is from this characteristic that the order Orthoptera (ὀρθός, straight, and πτερόν, wing) is named.

The wings of the adult Rhomaelia cover only one half of the abdomen, and are, therefore, rudimentary. Where the wings are functional they extend beyond the end of the abdomen. The outer pair is leathery in texture and forms a protective coat over the membranous pair folded like a fan underneath.

The *legs* are true appendages, modified for walking and jumping. There is a pair on each segment, the first two pairs being used for walking and grasping food, while the third pair is greatly enlarged and is used for jumping. Each leg is attached on the lower posterior border of a pleuron, by means of an arthropodial membrane. The third pair push back into the first segment of the abdomen and push the tergite and sternite apart.

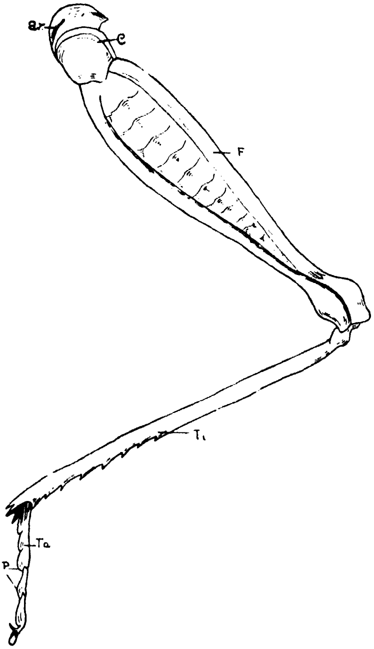

Fig. 7.—Jumping leg of *Rhomaelia microptera*. *C*, Coxa; *ar*, arthropodial membrane; *F*, femur; *Ti*, tibia; *Ta*, tarsus; *P*, pulvilli.

All muscles of the grasshopper are striated and the slender, bandlike muscles of the appendages are inserted in the body wall. Their strength is shown by the fact that the grasshopper leaps many times the length of its body.

The segments of all legs are the same except that in the third pair the femur and tibia are greatly enlarged for jumping.

The *coxa* is the globular segment which is joined to the body by the arthropodial membrane.

The *trochanter* is a small joint incompletely fused with the next segment.

The *femur* is a long, powerful segment, much enlarged in the jumping leg.

The *tibia* is more slender than the femur but about the same length so that it is also enlarged in the jumping leg. The inner surface bears a row of spines.

The *tarsus* is the terminal part of the leg and has three joints and five ventral pads, the *pulvilli.* The tarsus ends with a pair of hooks.

Abdomen

There are eleven abdominal segments, although the last is a mere rudiment. With the exception of the first and last, all segments are alike, and, except for the ovipositors, all are typically lacking in appendages. The pleura are practically lacking, the only vestige being the membrane between the sternum and the tergum which curves down over the sides like a shield on each segment. The spiracles are on the lower borders of the tergites, just above the membranous junctions.

On the first abdominal segment the tergum and sternum are pushed apart by the insertions of the jumping legs and the sternum is fused to the sternum of the metathorax. The *tympanic membranes* are stretched across openings in the sides of the tergum. A chitinous ring surrounds each membrane, holding it taut. The spiracle of the first segment is on the anterior edge of the tympanic membrane.

The ninth and tenth segments are narrower than the rest, and partially fused. From the tergum of the last complete segment there extends a broad triangular plate, the *suranal plate,* which forms the roof for the anal opening. This is the rudiment of the eleventh segment.

A pair of small, pointed processes extend posteriorly from the tenth segment, the *cerci.* These may be appendages. Under each is a triangular podical plate which may also belong to the eleventh segment. The anal opening is between the two podical plates.

On the male grasshopper the ninth segment is followed ventrally by a triangular plate which curves upward. This is the *subgenital plate.* It terminates dorsally in two short spines. The male genital opening is at the end of the *penis* which terminates in a hard point just under the subgenital plate.

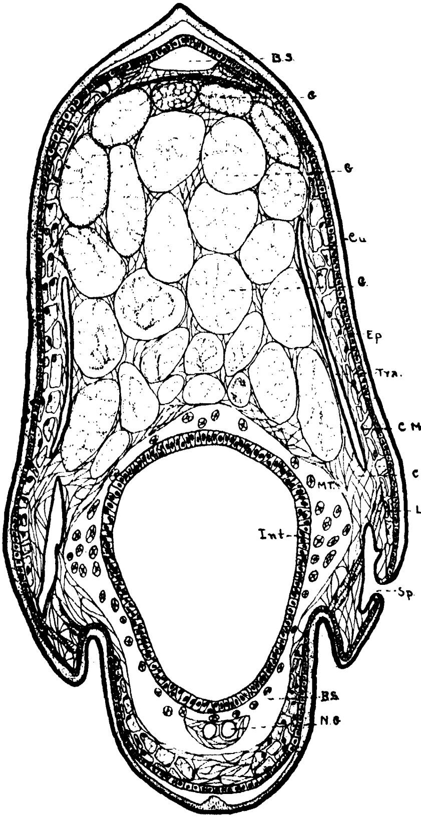

Fig. 8.—Transverse section through abdomen of male grasshopper. *Rhomaelia microptera.* *B.S.*, Blood sinus; *G,* gonads in various stages of maturation; *Cu,* cuticle; *Ep,* epidermis; *Tra,* tracheal tube; *C.M.*, circular muscle; *L.M.*, longitudinal muscle; *C.T.*, connective tissue; *M.T.*, malpighian tubule; *Int,* intestinal wall; *Sp,* spiracle; *N.G.*, nerve ganglion. (Original drawing by Elizabeth Drumtra.)

On the female grasshopper the abdomen ends ventrally with the eighth sternum from which the egg guides project posteriorly. Two pairs of hard pointed *styles* form the *ovipositors.*

These are true abdominal appendages, and extend back from the eighth segment on either side of the genital opening at the base of the egg guide.

INTERNAL STRUCTURE

The organs of the body cavity are known collectively as the *viscera.* They fill the body cavity completely, the body wall expanding to accommodate a greater or less bulk according to the state of the reproductive organs. In the fall, when the eggs are ripe, the abdomen of the female will be much distended, and the ovaries will almost completely conceal the other organs.

The cavity is moist, all space being filled with the body liquid, the *lymph,* which is the colorless blood of the insect. The absence of hemoglobin is due to the specialized type of respiratory system which carries the oxygen to the tissues without the aid of the blood.

The presence of the body cavity may be demonstrated by lifting the organs apart. They are separate from one another, and no partitions, mesenteries, or spongy tissues surround them. The absence of partitions is a mark of specialization, the segmentation of the animal being external only.

The bandlike *muscles* of the appendages lie on the inside body wall of the thorax. Numerous yellow *fat bodies* are attached to the viscera here and there and to the body wall as well. In among the muscles and fat bodies of the upper thorax are the *salivary* glands, clusters of round bodies connected by a duct to the mouth cavity.

Organs of Respiration

The *tracheae* are glistening white ducts which are outgrowths of the body wall and are lined with chitin. This thickens locally to form spiral bands. There are three main trunks which communicate with the spiracles by very fine tracheal ducts, and which ramify through the body with finer and finer subdivisions until they end with single cells. In the thorax they enlarge occasionally into *air sacs.*

The tubes are everywhere surrounded by blood *sinuses* so that they are at all times in contact with the lymph. Since the branches end in single cells, the air entering through the spiracles is brought into direct contact with every part of the body at one time. This is considered the most efficient respiratory system in the animal kingdom.

Organs of Digestion

The digestive tract lies in the center of the cavity. There are no breaks in the tract from the *mouth* which leads into a narrow *esophagus* to the *anus* at the end of the *rectum*. It is, therefore, a tube with external openings at the anterior and posterior terminations. The tube is uncoiled, and, therefore, the exact length of the body—a tube within a tube. The cavity of the external tube is the body cavity and that of the internal tube is the digestive cavity. There is no connection between the two cavities, and the contents of the inner tube are still outside the body, and are poisonous to the body. Death, or serious disease, results from any perforation of the intestine which allows the contents to come in contact with the body cavity.

The organs of the digestive tract are formed by dilatations of the tube with various modifications of the walls. All variations of the digestive tract in the animal kingdom are due to the number and type of the dilatations, and to the increased surface of the linings caused by the coiling of the intestine, or by the infolding of the lining. The length of the intestine comes finally to measure several times the length of the body itself.

The *salivary glands* are a part of this system. The ducts open into the mouth cavity, showing that they are outgrowths of the tube. The *esophagus* leads from the mouth to the beginning of the thorax, turning a sharp angle where the head joins the body. Here a dilatation of the tube forms the *crop,* a large organ occupying the whole thoracic cavity. As the tube enters the abdomen, a second dilatation forms the *stomach,* or ventriculus, which runs to the seventh abdominal segment. At the center of the stomach a ring of six glands is

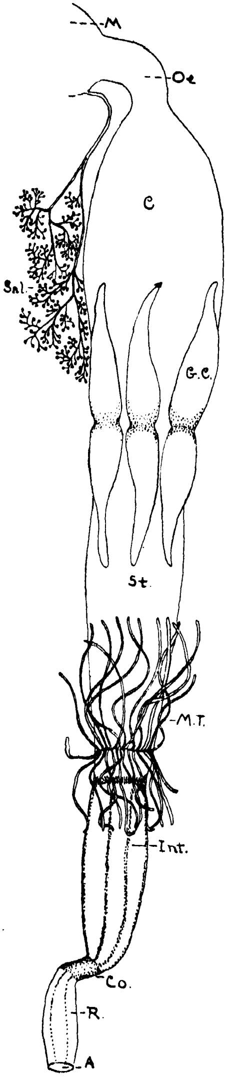

Fig. 9.—Digestive system of *Rhomaelia microptera*. *M*, Mouth; *Oe*, esophagus; *C*, crop; *Sal*, salivary glands; *G.C.*, gastric caeca; *St*, stomach; *M.T.*, malpighian tubules; *Int*, intestine; *Co*, colon; *R*, rectum; *A*, anus. (Dissection and drawing by Elizabeth Drumtra.)

found, the *gastric caeca.* These are outgrowths of the stomach wall and are attached by their central part to the stomach wall in such a way that one half extends into a pointed sac in each direction, forward and back. They almost completely conceal the stomach, but their point of attachment marks the division of the stomach into a proventriculus and a ventriculus proper. This is not sharply differentiated in Rhomaelia, but in most grasshoppers, the proventriculus has thickened chitinous bars in the lining which grind the food. It is then called a gizzard.

The stomach narrows slightly into the *intestine,* the constriction being marked by a ring of threadlike tubes, usually presenting the appearance of a matted yellow mass of threads. These are the *malpighian* tubules, or the *uriniferous* tubules.

The intestine extends to the tenth segment where it narrows into a short *colon,* which widens in the eleventh segment to form the *rectum.* On the surface of the rectum are six expanded areas, the *rectal glands.* Between the glands, long muscles extend from the rectum to the body wall, giving to the organ the power of forceful ejection of the feces. These form into cylindrical pellets and are often found in the rectal cavity.

Organs of Circulation

Examination of the dorsal strip removed at the beginning of the dissection will reveal the heart as a long, tubular structure, slightly constricted at intervals. The sides are pierced by openings, the *ostia,* and the heart is attached to the body wall by means of *alary muscles.*

Contractions of the alary muscles cause the dilation of the heart, and this draws the blood in through the ostia. The blood leaves the heart through the anterior opening where it enters large blood spaces, called *sinuses,* which constitute the body cavity. A sinus is morphologically an enlarged blood vessel, and this type of body cavity is called *hemocoele.*

Organs of Reproduction

Female Organs.—In the female two ovaries will be found in the posterior half of the abdomen. Each comprises several parallel *ovarian* tubes which slant in from either side

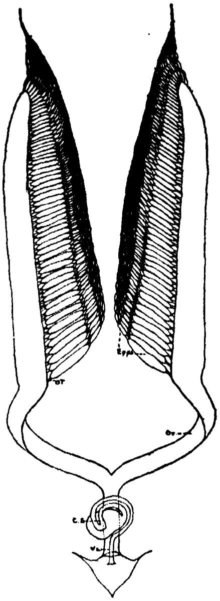

Fig. 10.—Female reproductive organs of *Rhomaelia microptera*. *O.T.*, Ovarian tube with eggs; *Ov*, oviduct; *C.S.*, copulatory sac; *Va*, vagina. (Dissection and drawing by Elizabeth Drumtra.)

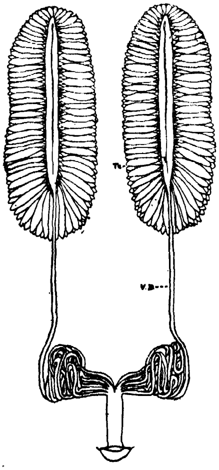

Fig. 11.—Male reproductive organs of *Rhomaelia microptera*. *Te*, Testes; *V.D.*, vas deferens. (Dissection and drawing by Elizabeth Drumtra.)

toward the two *oviducts,* with which each ovarian tube is continuous. The eggs will be found in the ovarian tubes in various degrees of maturity, the riper ones being closest to the oviduct. If the female is immature, the ovarian tubes may appear entirely empty, in which case they will occupy very little space.

The eggs are oval bodies so that the tubes taper off toward the body wall where the immature eggs are, and, as they slant from dorsal to ventral, the union of the two oviducts will be found ventral to the intestine. The common duct is the *vagina* into which the oviducts empty the ripe eggs. It opens to the outside by the female genital opening at the base of the *egg guide.*

Just dorsal to the vagina is a *copulatory sac* which receives the sperm from the male. It joins the vagina before reaching the genital opening so that both eggs and sperm leave the body together. The two styles of the ovipositor are on each side of the egg guide. Being true appendages, these are the organs which dig into the soil, making a hole to receive the fertilized eggs. The genital opening is protected when not in use by a cushion at the base of the egg guide which folds over it.

Male Organs.—The *testes* form a single white mass lying dorsal to the intestine. Two tubes, the *vasa deferentia,* lead from the ventral surface to the posterior end of the seventh abdominal segment, where they coil up. The coils occupy the seventh and eighth segments, and unite in the midventral line to form a single duct which passes into the muscular mass surrounding the *penis.* The penis is composed of four hard, chitinous styles which are used in transferring the sperm to the copulatory sac of the female.

Organs of Conduction

The nervous system lies against the ventral body wall and is composed of *ganglia* connected by *commissures.* Ganglia are concentrated groups of nerve cells and commissures are connecting fibers. In a typical metameric animal the ganglia would be found in every segment, but the grasshopper is specialized and this condition exists only in the thorax where one large ganglion is found in each segment. In the abdomen the ganglia do not correspond with the segmentation, and there are but five, several being concentrated into one. Each ganglion is in reality two ganglia fused, as can be seen in the double nature of the commissures.

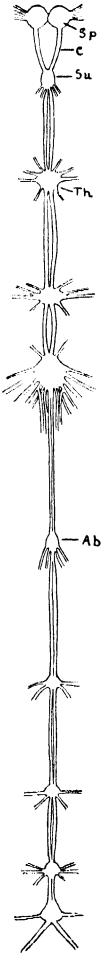

Fig. 12.—Nervous system of *Rhomaelia microptera.*—*Sp,* supraesophageal ganglion; *C,* circumesophageal commissure; *Su,* subesophageal ganglion; *Th,* first thoracic ganglion; *Ab,* first abdominal ganglion. (Dissection and drawing by Elizabeth Drumtra.)

In the head, cephalization has taken place, and a definite brain is established on the dorsal side of the esophagus between the compound eyes. It is also a double ganglion, and from it run fibers to the sense organs of the head, the optic nerves connecting with the pointed cones of the *ommatidia.*

The brain is technically a supraesophageal ganglion. It is connected by means of two commissures which curve around the esophagus to the subesophageal ganglion below. This nerve ring through which the digestive tract passes, is typical of the invertebrate nervous systems. In all vertebrates the nervous system is entirely on the dorsal side and no such arrangement is necessary to bring the brain to the dorsal side of the head.

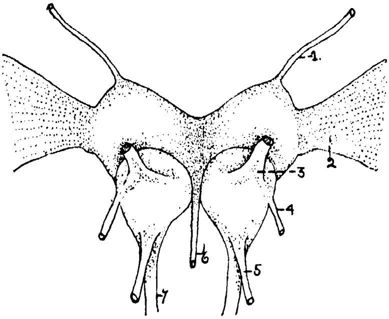

Fig. 13.—Anterior aspect of brain (supraesophageal ganglia) of *Rhomaelia microptera* (magnified). *1*, Nerve to paired ocellus; *2*, nerve to eye, showing fibers to ommatidia; *3*. nerve to antenna, *4*, and *5*, nerves to mouth parts; *6*, nerve to unpaired ocellus; *7*, circumesophageal commissure. (Dissection and drawing by Elizabeth Drumtra.)

CHAPTER III

THE LIVING ANIMAL

The grasshopper is a living organism. As such it must be self-preserving and race-preserving, and must be in continual interaction with its external environment.

Self-preservation is accomplished by the repair of tissues broken down by muscular exercise. The need for repair is an internal stimulus which can only be satisfied by the acquisition of fuel to burn. The automobile which has used up all its fuel ceases to move; the grasshopper goes after more fuel before the supply is so completely exhausted as to prevent motion. This is necessary because it cannot make immediate use of the fuel. The procuring of food is, therefore, the first reaction to the internal stimulus evoked by the need of fuel. It is a reaction which brings the grasshopper into immediate contact with its external environment.

FOOD TAKING

The food of Rhomaelia, the Florida grasshopper, consists chiefly of the leaves from the orange trees. Our local varieties feed largely on grass blades. These are both adequate diets, for they contain all the elements necessary for growth and oxidation, namely, carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) in the form of carbohydrates, proteins, and fats. In this the food differs from the fuel of the automobile, for it must contain the materials not only for burning but for repair of the machine as well. The carbon, hydrogen, and oxygen (carbohydrates and fats) will be used in oxidation; but the nitrogen compounds (proteins) will contribute directly to the making of new tissue.

The type of food eaten limits the distribution of the grasshopper. Where there is no grass or green leaves, there will be no grasshoppers. Even granted the presence of grass, it does not grow on every spot. There are sandy roads and cement walks that come between the grasshopper and the food which he must have. This necessitates a reaction which will bring the organism into adjustment with its external environment. He must find the food. For this purpose he has sense organs which are irritable to certain external stimuli. The compound eyes are the most prominent. They are sensitive to light and probably to images, while the pigment around the lenses is believed to be sensitive to the ultraviolet rays. Thus the world visible to the grasshopper must have a very strange appearance, color as perceived by man being wholly invisible. The large number of the lenses insures extreme sensitivity to motion, the least trace being detected whether in front or behind the animal. It is as a warning organ that the eye functions primarily,

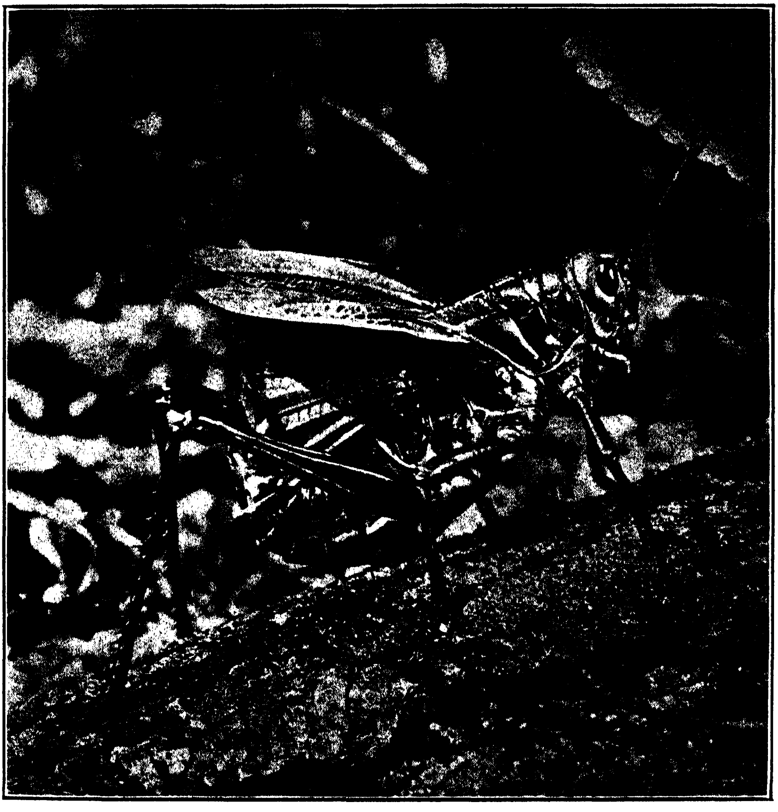

Fig. 14.—*Rhomaelia microptera* (life size). (Photograph and copyright by H. R. Bezant. Reproduced by permission.)

although the attraction to light aids in locating food. The *antennae* are the organs which detect food at a distance, for they are irritable to chemical odors as well as to touch.

The warning organs are quite as essential to the procuring of food as the organs which locate it, for the grasshopper has many enemies, and to accomplish self-preservation it must escape from their clutches and, at the same time, reach the food. In addition to the eyes, the *tympanic membranes* warn of the approach of danger by responding to vibrations of the ground. In case the threatened danger overtakes the grasshopper, he has certain protective equipment which enables him to elude less crafty enemies. The *exoskeleton* is hard, forming a complete coat of mail about the head and thorax. Many animals find this distasteful; therefore, it is his chief organ of protection. He secretes, in addition, a disagreeable *brown juice* from the crop which often causes his enemies to drop him in disgust.

To reach the food or escape from danger there must be an active response to the sensations received. The grasshopper jumps, the leap being several times the length of the body. If it has functional wings, it may also fly. Rhomaelia must depend entirely upon jumping. This is a motor reaction caused by the release of energy in the *muscles* of the *legs* or *wings*.

Every reaction is a response to a stimulus. In this case the stimulus entered the body by means of the antennae on the head; the response was made by the jumping legs on the metathorax, at least half the length of the body from the receiving organs. In some way the stimulus has been conducted from the sense organ to the muscle. This is accomplished by the fibers of the *nervous system,* the fundamental function of which is the conduction of stimuli. It is also true of the nervous system that it coordinates the work of the organs so that they act as a whole; but, as this is the result of the fundamental function and not the cause, it cannot be used to denote the function of nerve material. Besides, there is the possibility that in the higher animals a system of chemical coordination exists. Conduction, therefore, shall be considered the function of the nervous system.

Tropisms.—The use of the word "tropism" is a questionable one but is preferable to any other yet devised to include the reactions to stimuli in the lower organisms. It is used here in the sense of a predictable response to simple stimuli. To predict the response of a living organism to simple stimuli, such as heat, light, etc., it is necessary to account for changes both in the external and the internal environment. The grasshopper will show no reaction to temperatures between about 20°-30° C., its optimum range, but will react negatively to temperatures above and below this range. In a similar way, changes in the internal environment must be accounted for.

What is known as the physiologic state of any organism is the chemical condition of the protoplasm. When in need of food, we say the physiologic state is one of hunger; when excessive use of muscles has exhausted the stored food material, we say it is a state of fatigue. When the state of hunger exists, the response of the grasshopper will be positive to food; but if the state of fatigue exists also, the response may be weak or absent. In case of two stimuli occurring simultaneously, the one to which the organism is the most sensitive will obliterate the response to the other, regardless of its intensity or of the harm which it may cause. Thus insects are often attracted to the street lights at night where they are ultimately killed by the excessive heat. Ordinarily they would have responded negatively to heat and been protected.

In the grasshopper, definite nerve paths are established for the conduction of the stimulus. These constitute the *reflex arc,* which includes one sensory and one motor nerve cell, or neuron. In the grasshopper simple reflex arcs exist, and there is also a brain, of scarcely more complexity than the ganglia of the ventral nerve cord, but still, by advantage of its dorsal position, a brain. Just how much of consciousness, and how much of choice may be attributed to this minute group of nerve cells is a debatable question. What is certain is that in general its reactions are predictable, and that, given cognizance of the internal state at any time, they would be predictable with a still greater degree of accuracy. Therefore, the word "tropisms" is used as synonymous in this case with reflex action, but is more adaptable to lower than to higher forms of life.

The reaction of the grasshopper to light is positive *(phototropism)*, to high temperature is negative *(thermotropism)*, to food and to the opposite sex is positive *(chemotropism)*, and to touch is negative *(thigmotropism)*. There are many other reactions, but these familiar ones will suffice to show that the grasshopper is in constant reaction with its external environment.

The reactions appear to be adaptive; that is, the positive reactions are such as bring him into favorable conditions for procuring food and the negative ones tend to remove him from danger. These two conditions, therefore, are essential to self-preservation in the organism. The need arises internally in the processes of tissue repair. Therefore, the life of the organism is one continual adjustment of the internal to the external environment, and every organ concerned plays some definite part in the adjustment.

The behavior of the organism is the sum total of these reactions, and it may be noted that the functions involved make use of more physical than chemical phenomena since the passage of a stimulus along a nerve is believed to be a phenomenon of electrical activity. There is some chemistry involved, however, since neurohormones are now believed to carry stimuli across the synapses in the invertebrates as well as in the vertebrates.

The fate of the food in the animal, however, involves strictly chemical changes. Therefore, to assist the student in summarizing the events described, we may distinguish between the *physical functions of behavior* and the *chemical functions of nutrition.*

SUMMARY OF THE PHYSICAL FUNCTIONS OF BEHAVIOR

Sensation: Antennae, compound eyes, ocelli, maxillary and labial palps, hypopharynx, tympanic membrane.

Conduction: Supraesophageal and subesophageal ganglia, circumesophageal commissures; three thoracic and five abdominal ganglia with connecting commissures.

Locomotion: Two pairs walking legs, one pair jumping legs, an outer and an inner pair of wings located on the thorax.

Protection: Chitinous exoskeleton composed of sclerites.

Fate of the Food

The food, once captured, is eaten. For this process the forelegs and mouth parts function, the legs grasping, the palps testing, and the mandibles biting the food. The secretions from the *salivary glands* moisten the food in the mouth cavity from which it passes through the *esophagus* to the crop where it may be stored for future use. What passes periodically into the stomach is masticated by the chitinous bars on the lining of the *proventriculus,* and is digested in the ventriculus by means of the gastric secretion from the glands surrounding the stomach. The digested food is absorbed through the wall of the *stomach* and *intestine;* the undigested food passes on through the *colon* to the *rectum* where a cylindrical, hard pellet is formed which is forcibly egested by the muscles of the rectal wall.

Digestion is a process by which the complex foods eaten are split into the molecules of which they are composed. It is not possible for the tissues of the grasshopper to make grasshopper protoplasm out of the protoplasm of grass without first simplifying it. In the first place, it would be impossible for such large molecules to pass through the intestinal wall and, in the second place, the carbohydrates, proteins, and fats are arranged in different combinations in the cells of a grasshopper and in the cells of grass. By splitting the food compounds into their constituent molecules, therefore, rearrangements can be made in each tissue, the cells choosing the building blocks best suited to their individual needs.

Splitting of the food molecule is called *digestion.* Chemically it is a process of *hydrolysis.* It can be accomplished only in the presence of *enzymes,* the chemical catalysts which speed up all body reactions without taking any part in them. The foods consist of the complex compounds of *carbohydrates, proteins,* and *fats.* By the process of digestion the carbohydrates are reduced to the simple sugars, of which *dextrose* is the common form; proteins are split into *amino acids,* and fats into *fatty acids* and *glycerin.* These are all soluble compounds and are passed through the intestinal wall by the process known as absorption.

It will be remembered that the body cavity of the grasshopper is one large blood space, a *hemocoele.* Into this space the digested foods are received and are immediately in contact with the lymph which is the colorless blood of the grasshopper. As the *alary muscles* of the heart contract, the lymph containing the food substances is drawn into the heart through the *ostia.* Subsequent contraction of the walls forces the blood through the opening at the anterior end so that it reaches the head and the blood spaces of the anterior end. This type of open circulation is sufficient to keep the lymph in motion, since the body cavity is not large.

The food will reach all the cells in this manner and there it will come in contact with the oxygen. Respiration takes place through the *spiracles* which are the openings found on either side of each segment of the exoskeleton. These open into the *tracheal ducts* which ramify through all the body, as described in the last chapter. This is truly the most efficient respiratory system in the animal kingdom, for the ducts are surrounded by blood spaces and carry the oxygen direct to the cells. Without the intervention of an oxygen carrier, therefore, the gas reaches its goal, and the carbon dioxide is returned to the air.

The dextrose which is the end product of carbohydrate digestion is the main fuel of the body. It contains stored energy which can be released only by a process known as *oxidation.* This is an internal respiration; the exchange of oxygen and carbon dioxide through the spiracles is a mere osmotic exchange of gases. It is the internal respiration that involves the chemical change. When oxygen joins the dextrose molecule, the stored energy is released and the dextrose molecule is split apart. Carbon dioxide and water are formed as waste products of oxidation. The carbon dioxide returns to the atmosphere through the spiracles.

The energy released by the process may be used by the grasshopper as motion, as when he jumps or flies, or it may be used as chemical energy to cause tissues to grow. Some of the energy is released as heat.

The general term of *metabolism* is used to cover all of the biochemical activities of protoplasm. It includes the constructive phases of maintenance, growth, and storage. This is called *anabolism.* It is an *endothermal* process, for it stores energy. For every anabolic process there is a *katabolic* one which is destructive, or *exothermal.* Energy is released and the end products of katabolism are wastes and must be excreted.

Since the energy needed by the animals for all metabolic activities is stored in the dextrose of the carbohydrate foods and can be released only by *oxidation,* the oxygen from the atmosphere is necessary to initiate any act of metabolism. This is furnished through respiration. Oxidation is an exothermal process, for it releases energy. Its reverse process chemically is *reduction.* The reduction process which completes the oxidation cycle cannot be performed in animal tissues. This is the only metabolic activity which is not completed in the animals. The reduction process which is needed to complete it is found in the green plants. Thus plants are necessary to the continued existence of animals.

It is to make possible the activities of metabolism that food is eaten, digested, absorbed, and circulated and that oxygen is inhaled. Conversely, it is only through the activities of metabolism that food can be captured, digested, absorbed, and circulated or that oxygen can be inhaled, for metabolism is the essential life process.

Excretion

Special organs are usually provided in animals to excrete the nitrogenous waste from the katabolic activities in the cells. In the grasshopper this is accomplished by the *malpighian tubules* which surrounds the intestine. These tubules absorb the waste in solution in the body cavity and pass it into the colon. There it is combined with the undigested food from the intestine, and in the rectum most of the water which entered through the malpighian tubules is reabsorbed into the body cavity so that the pelletlike masses excreted are quite dry.

Removal of undigested food in animals is called *egestion* to distinguish it from the *excretion* of the nitrogenous waste. In the grasshopper the two functions are combined. This is a peculiarity in insects and is not characteristic of other animals.

Storage

The yellow fat bodies in the grasshopper act as organs of storage where food can be kept in reserve until needed. Food is always stored in an insoluble form. Since the digested foods are soluble, they must be rebuilt into the original form. Thus fatty acids and glycerin will recombine into fats, and molecules of dextrose will combine to form an animal type of starch, glycogen. This rebuilding process is called *condensation*. It is constructive and endothermal and is the reverse of *hydrolysis* or digestion. As these are reversible processes, sugars can be built into starches and starches split into sugars at any time. Enzymes to activate the processes are found in all cells. In the higher animals the liver and the muscles act as storage organs for glycogen.

Summary of the Chemical Functions of Nutrition

Digestion: Salivary and gastric glands; esophagus, crop, stomach.
Absorption: Through walls of stomach and intestine.
Circulation: Tubular, ostiated heart, blood spaces, lymph.
Respiration: Spiracles, tracheae.
Excretion: Malpighian tubules, colon, rectum, anus.

RACE—PRESERVATION

The only organs of the body, external or internal, not needed for daily activities of self-preservation are those of the reproductive system. These are needed only periodically and are subject to seasonal activity, lying dormant the greater part of the time. Coincident with the activity of these organs are complete change in behavior reactions, certain tropisms being firmly fixed at this time which do not exist at other periods.

The special reactions of sex usually involve the finding of the mate and the actual copulation process. The grasshopper finds the female by means of the antennae, for when these are removed, he does not approach the female even though right beside her. It is by the sense of smell, therefore, that the mating is accomplished.

The male places the *penis* in the female genital opening and inserts the sperm in the female *copulatory sac.* There they remain until the ripe eggs pass from the *ovaries* to the

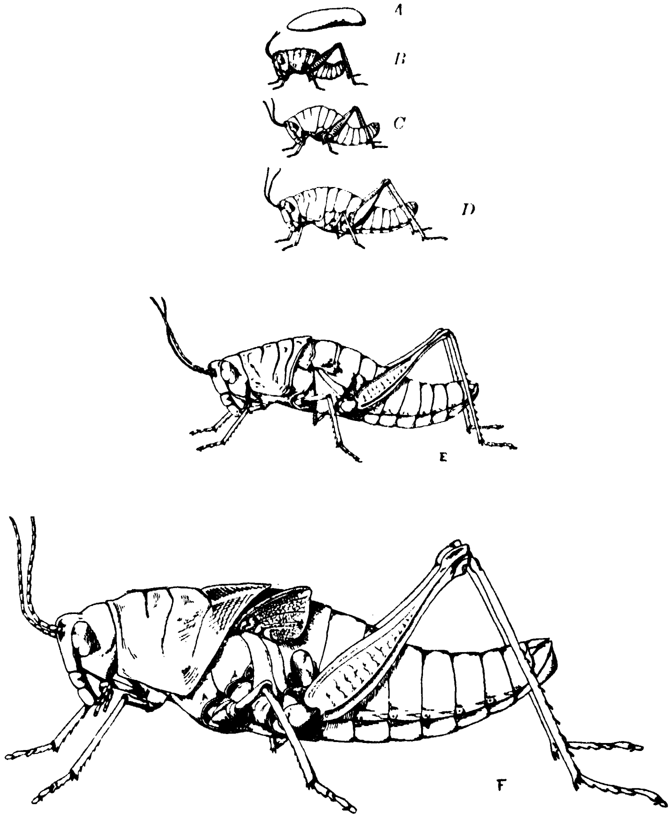

Fig. 15.—Metamorphosis of *Rhomaelia microptera*. *A*, Egg; *B*, nymph just hatched; *C, D, E, F,* successive stages in development (life size). (Original drawings by Eleanor Sloan Hough.)

oviducts and thence to the *vagina.* They are passed out through the genital opening together with the sperm in a little sac. The ovipositors dig actively in the ground, making a hole in which the sac is placed. This takes place during the fall, and the young grasshoppers hatch out the following spring.

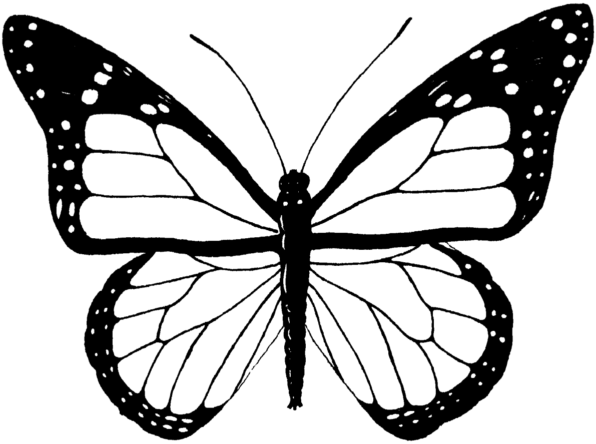

Fig. 16.—Monarch butterfly (life size). (Original drawing by Eleanor Sloan Hough.)

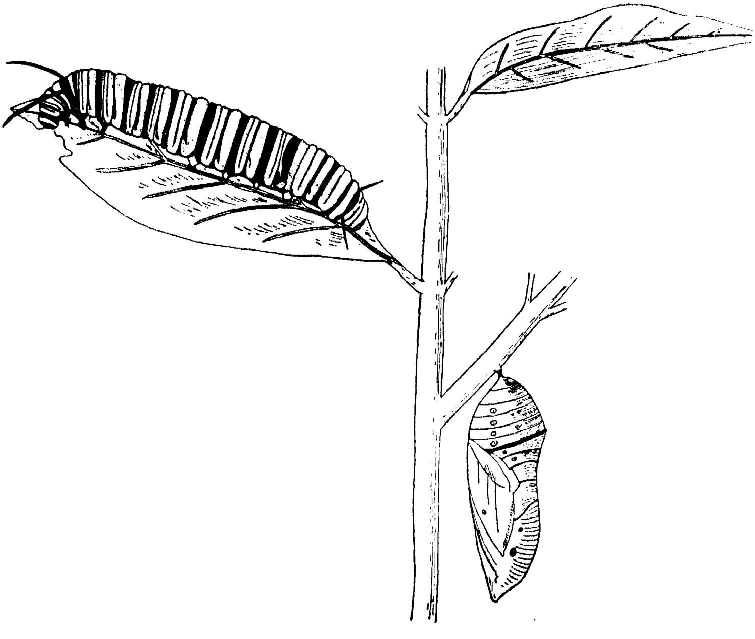

Fig. 17.—Monarch butterfly. Larva and pupa on a milkweed plant. Stages in complete metamorphosis. (Drawn by Amy Logan.)

THE ORGANS OF REPRODUCTION

Male: Testis, vasa deferentia, penis.
Female: Ovaries, oviducts, vagina, copulatory sac, ovipositors.

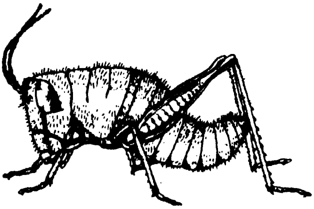

Fig. 18.—Nymph just after hatching. An enlargement of Fig. 15, *B*.

Metamorphosis

When the grasshopper first hatches, its proportions are quite infantile, and it is broader than it is long. It is a stage of very active feeding and the little grasshopper grows rapidly. But the exoskeleton does not grow. Instead, being a secretion and nonelastic, it gets tight and splits down the center of the back, so that the grasshopper steps out of the tight jacket, leaving its perfect form behind. This is the process of *ecdysis*.

After each ecdysis, the grasshopper assumes a little more of the adult shape and has slightly longer wings. This gradual change in shape during the growth period is called *metamorphosis* (change of form). In the grasshopper the process is gradual, but in many of the insects we find a complete metamorphosis. The moth and the butterfly are the best examples, for the *caterpillars* are often different in color as well as in form and shape. The metamorphosis here takes place inside a cocoon which is a silky case spun by the caterpillar after it has fed itself like a glutton for a sufficiently long time. Inside the cocoon a complete reorganization of protoplasm takes place, the moth or butterfly which hatches from the cocoon bearing no slightest resemblance to its more earthly youth. In keeping with their winged state and their exquisite beauty, the life of the adults is very short. They live only to mate and lay the eggs of the next generation.

CHAPTER IV

CLASSIFICATION OF THE GRASSHOPPER

The study of any organism is incomplete until its place has been found in the files of Nature. Classification is an arbitrary means of sorting and sifting the living organisms into some semblance of order. The difficulties of so dealing with more than a million species are great, and not until the modern view of genetic relationships became the basis of classification could any real order come out of the confusion.

The early taxonomists based everything on the external form which often carried them far afield. Thus *Carolus Linnaeus,* who published the first comprehensive scheme of classification in the *Systema Naturae* in 1735, made the glaring error of including in one genus a jellyfish, a worm, a sea cucumber, and a sea squirt. These forms are now known to belong to the widely divergent groups, ranging all the way from the most primitive invertebrates to some of the ancestral vertebrates.

Many mistakes of this kind are found in his work, but that does not in any way minimize the importance of Linnaeus' contribution to classification. It is to him that we owe the standardization of the scheme of Latinizing terms so that common endings could be used, and genus and species names recognized at a glance. This is the so-called *binomial nomenclature.* The generic name always begins with a capital letter, and the specific name with a small letter as though John Jones were to write his name Jones john. Thus the grasshopper which has just been described is known as *Rhomaelia microptera.* Sometimes a subspecies is recognized, in which case a third name is added, as in the western variety of our common robin, known as *Turdus migratorius propinquus.*

Even today there are many differences of opinion and each investigator with a new and cherished idea has started a classification of his own. But the sound basic principle of genetic relationships holds universally, for it has been recognized that a classification can be of no real value if it does no more than file the species away for convenience.

Several attempts have been made to bring classifications under some general law and to standardize nomenclature. Uniformity of Latinized endings for classes, orders, families, etc., is constantly being sought and recognition of the law of priority in the naming of animals and plants is generally recognized. By this law the name given to any genus by the first accurate observer will be accepted, regardless of its appropriateness. By common consent the claims of priority do not go back farther than 1758, but any name assigned since that date must be given first consideration. This custom has been the cause of much confusion and some amusement, for, in their search for the prior claim, the common bedbug changed its name six times within one year, and the classic Amoeba has been threatened with the name of Chaos. So far the claims of common usage have outweighed the priority law in this case, but there are still strong adherents of priority pushing the claims of Chaos.

The basis of genetic relationship is common origin. Structures which are built upon a similar plan are *homologous* even though they may function differently. Thus the leg of a horse, the arm of a man, and the wing of a bird are homologous structures, containing the same bones and originating in the same order; even though modified for such different purposes as running, writing, and flying.

Analogous structures are those which are used for the same function but which differ in structure. The wing of a bird, the wing of a bat, and the wing of an insect are all used for flying; but the first two are built upon foundations of bone, the second has a flap of skin stretched across from fore to hind leg, while the third has a double fold of skin tissue growing out of the back. No classification would be valid which was based on analogies, but the common law of homologies can lead to only minor errors.

The Grasshopper. Its Place in Nature

The relationships of the grasshopper can be determined by the process of elimination, separating him first from the forms least like him and finally arriving at his nearest relatives. For convenience classifications make use of certain group terms.

Thus

Kingdoms include various phyla
Phyla include various classes
Classes include various orders
Orders include various families
Families include various genera
Genera include various species
Species include various individuals

The characteristics of each subgroup presuppose those of all higher groups. Thus all phyla have the characteristics of the kingdom to which they belong; all classes the characteristics of both phylum and kingdom. With each subdivision, however, more and more differences are involved, eliminating those organisms which, while sharing in the characteristics of the higher groups, cannot share those of the lower ones.

A full classification of the animal kingdom will be found in Chapter XXX.

The accompanying outline shows by progressive elimination groups of organisms listed to show increasing resemblance to *Rhomaelia microptera*, the Florida lubber grasshopper.

THE ANIMAL KINGDOM

(nutrition holozoic)

Excluding:	*Including:*
All plants	All animals

Subkingdom: Invertebrata

(lacking in bone or notochord)

Fishes	Protozoa
Frogs	Jellyfishes
Reptiles	Worms
Birds	Shellfishes
Mammals	Starfishes
	Crabs
	Spiders
	Insects

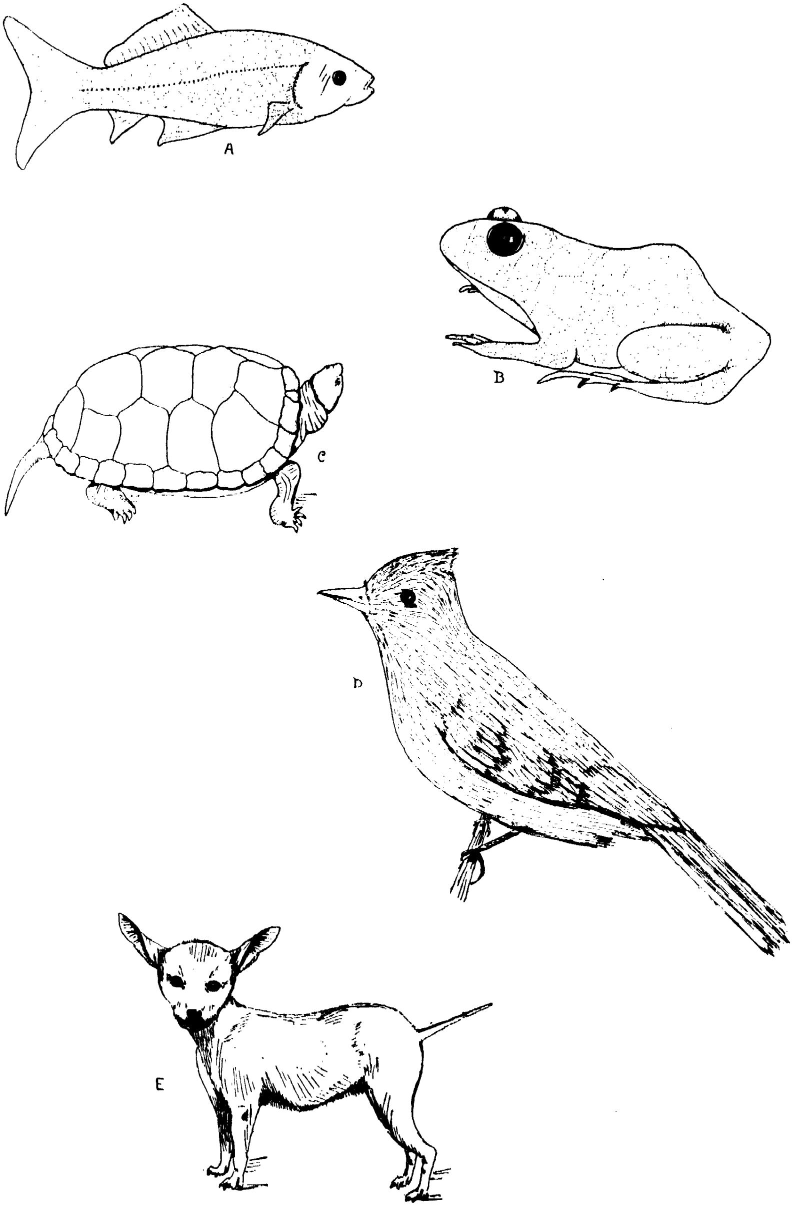

Fig. 19.—Vertebrate types. *A*, Fish; *B*, frog; *C*, reptile (turtle); *D*, bird; *E*, mammal. (All redrawn by Claire King.)

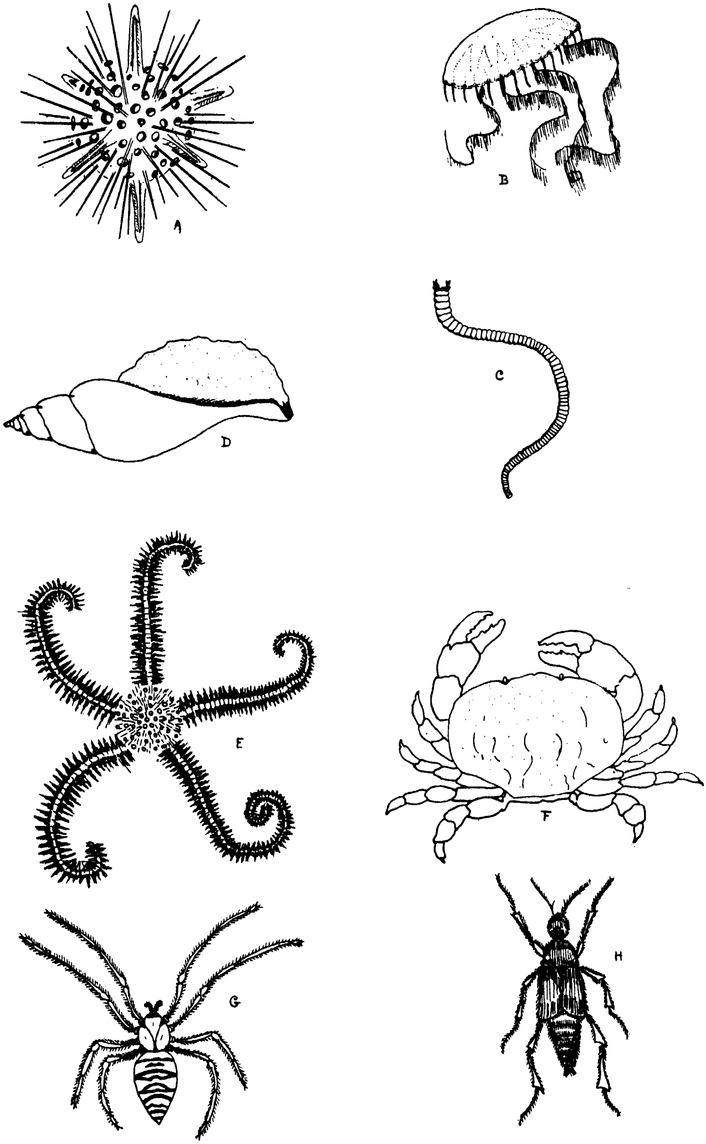

Fig. 20.—Invertebrate types. *A*, Protozoan, magnified; *B*, jellyfish; *C*, worm; *D*, shellfish; *E*, starfish; *F*, crab; *G*, spider; *H*, insect. (All redrawn by Claire King.)

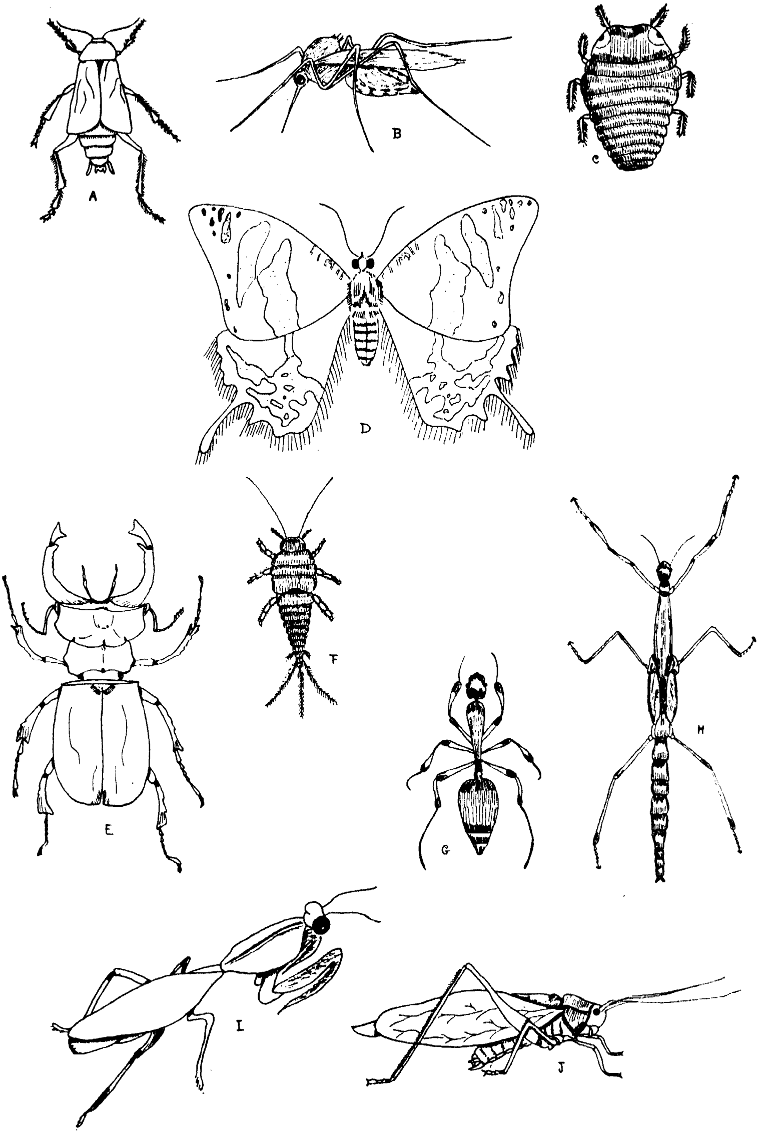

Fig. 21.—Insect types. *A*, Cockroach; *B*, mosquito; *C*, grape louse; *D*, butterfly; *E*, beetle; *F*, silver moth; *G*, ant; *H*, walking stick; *I*, praying mantis; *J*, katydid. (All redrawn by Claire King.)

Excluding	Including

Division: Metazoa

(animals with tissues or organs)

Protozoa	Jellyfishes
	Worms
	Shellfishes
	Starfishes
	Crabs
	Spiders
	Insects

Phylum: Arthropoda

(animals with jointed appendages)

Jellyfishes	Crabs
Worms	Spiders
Starfishes	Centipedes
Shellfishes	Insects

Class: Insecta (Hexapoda)

(3 pairs thoracic appendages)

Crabs	Grasshoppers
Spiders	Katydids
Centipedes	Cockroaches
	Mantes
	Walking sticks
	Butterflies
	Ants
	Beetles
	Mosquitoes
	Lice
	Silver moths

Order: Orthoptera

(straight wings)

Silver moths	Grasshoppers
Lice	Katydids
Mosquitoes	Cockroaches
Butterflies	Mantes
Beetles	Walking sticks
Ants	

Excluding		Including
	Family: Acrididae (short-horned)	
Long-horned grasshoppers Schistocerca Cockroaches Katydids Mantes Walking sticks		Rhomaelia Melanoplus Dissosteira
	Genus: Rhomaelia (Florida lubber grasshopper)	
Melanoplus Dissosteira		All Rhomaelia
	Species: microptera (short wings)	
All other species of Rhomaelia		Varieties of microptera

CHAPTER V

UNITS OF ORGANIZATION

Units Defined

Now that the grasshopper has been seen as a living organism, it remains to find out something of the organization upon which this union of systems and organs is built.

A *system* is a group of organs, the combined functions of which are directed to one end.

Example: The digestive system—composed of a series of organs including the esophagus, crop, stomach, etc., the combined functions of which are to collect the food, prepare it, and transmit it for the one purpose of digestion.

An *organ* is a group of tissues, operating collectively to perform a limited part of the function of the system.

Example: Stomach—composed of muscle, glandular and connective tissues which perform or make possible the functions of digestion and absorption.

A *tissue* is a group of similar cells, performing a similar function.

Example: Muscle—the muscles of the stomach wall are made up of a number of muscle cells which, by contracting in unison, cause the churning motion of the stomach.

A *cell* is a mass of protoplasm usually containing a nucleus. Some cells have no organized nuclei, however; some have multiple nuclei, and some lose their nuclei when mature.

Example: A muscle cell—a single elongated fiber containing a nucleus. Its sole function is to contract.

Protoplasm is a system of chemical compounds held together in a colloidal suspension, and containing among other elements, carbon (C), hydrogen (H), oxygen (O), and nitrogen (N), in the form of proteins, carbohydrates, and fats.

A *compound* is a chemical union of molecules.

Example: A protein is composed of many amino acids.

A *molecule* is composed of two or more atoms.

Example: An amino acid molecule contains carbon, hydrogen, oxygen, and nitrogen.

An *atom* is the ultimate unit of matter, not divided by any chemical means; it yields protons, electrons, and, in some cases, neutrons.

Example: The hydrogen atom contains one proton and one electron.

A *proton* is a unit of positive electricity.
An *electron* is a unit of negative electricity.
A *neutron* is a unit of energy without electric charge.

Since the functions of the grasshopper have been shown to have one common end in view—the act of metabolism—and since metabolism is a function of every cell, it follows that the cell is alive, and that it is the organization of the cells into tissues, organs, and systems, which makes the grasshopper a living organism.

Protoplasm

The contents of the cell thus become of paramount importance. Protoplasm is the living substance. Upon analysis it yields very constant results, in spite of the great variety of food eaten. The average percentage of the main elements based on the human body is as follows:

	Per cent
Oxygen	65.00
Carbon	18.00
Hydrogen	9.00
Nitrogen	3.00
Calcium	2.00
Phosphorus	1.00
Potassium	0.35
Sulphur	0.25
Sodium	0.15
Chlorine	0.15
Magnesium	0.05
Iron	0.004
Iodine, fluorine, silicon	traces

These elements are in protoplasm in the form of compounds, chiefly proteins with carbohydrates, fats, water, and salts in varying amounts and all held together in a *colloidal suspension.*

Colloids.—A *colloidal* mixture is one in which minute particles of varying sizes are held suspended in a formless substratum. The particles are larger than in a *solution,* where the material dissolved, the *solute,* is completely dispersed throughout the substratum, the *solvent.*

Hydration.—The function of a colloidal mixture is the power to absorb and hold water. This is *hydration* or imbibition.

Water constitutes about 58.5 per cent of the human body and 88 per cent of the bulk in bacteria.

Gelation.—As a result of *hydration,* protoplasm has the power of *gelation.* A jellylike colloidal mixture is a *gel.* By imbibing more water this becomes a *sol.* In protoplasm the process is reversible.

The formless substratum is the *hyaloplasm.* It constitutes the *external* phase of a colloidal system. The suspended particles constitute the *internal* phase. The passage from a *sol* to a *gel* state can be observed in a cooling gelatin. When the spherical globules of gelatin are more solid than the substratum, the condition is that of the *sol;* when the gelatin cools, the globules will become more liquid than the substratum which will have become relatively firm. This is the *gel* stage. The amount of firmness attained by the substratum is its viscosity. It depends upon the amount of hydration, since colloids have the additional function of remaining within the cell, while substances in solution may pass in and out.

Not all colloids have the power of gelation. Those which do are *suspensoids;* those which do not are *emulsoids.* Upon coagulation, colloids become irreversible. Thus the fibrin of blood which coagulates during the process of clotting is an irreversible colloid. All protoplasm coagulates after death. The reversibility of protoplasm, more than any other property, explains the remarkable diversity of cell activities. When the gel is formed from the sol there is always some liquid squeezed out by the contraction of the gel. Secretion is thought to be accomplished in this fashion. As the protoplasm increases in viscosity, it contracts and squeezes out the liquid which is the secretion. The contraction of a muscle may also be due to the property of gelation, the muscle alternately imbibing liquid and squeezing it out in the striated areas.

Molecular Movement.—The suspended compounds in a colloidal mixture are in constant motion. This movement which can be made visible under a microscope is not due to any energy in the visible particles, but to the movement of smaller invisible particles, the molecules.

Molecules are made up of atoms. Each molecule of water is composed of three atoms, two of hydrogen and one of oxygen (H_2O). A simple sugar has six atoms of carbon combined with six molecules of water ($C_6H_{12}O_6$, dextrose). Two molecules of dextrose can be combined to form a double sugar—($C_{12}H_{22}O_{11}$, sucrose).

The motion of molecules is due to the energy within the atoms, for each atom contains a nucleus of one or more *protons* around which one or more *electrons* are revolving in infinitesimal orbits with incredible speed. Hydrogen has the simplest atomic structure with one electron revolving around a single proton.

This motion transferred to the molecule sends the molecule in a straight line until it meets another molecule. Glancing off from the obstacle, it will proceed until it again hits another molecule. Thus the path of the molecule will be limited by the distance between molecules and, as a result, will be a zigzag one. In their path, molecules hit larger particles which move in the same direction until still larger particles are struck. Each particle magnifies the path until a visible motion is reached. This visible path of the larger particles is magnified molecular motion and is known as *Brownian movement.* It is the same movement seen in dust particles when a ray of sunlight makes them visible. It appears as a general dancing movement. It can be observed in protoplasm if a cell, such as amoeba, be crushed in water and examined against a dark-field. The dark-field is one in which the light enters the solution from the side. This prevents the dispersal of light and makes visible even very minute particles as bright spots against a dark-field. Any colloidal solution may be used for the purpose. Those with fairly large particles such as gamboge or India ink, are preferable.

Diffusion.—The distance which any molecule can travel without meeting another molecule determines the solidity of matter. Thus molecules of steel are closer together than molecules in a piece of wood, and the material is correspondingly firmer. In a liquid, molecules are much less confined but cannot escape from each other into the air except when vaporized by heat. This attraction is called *cohesive force.* In a gas, the molecules have no attraction for each other and are free to move throughout the atmosphere. Some liquids, like ether, are volatile;

that is, they will vaporize on contact with air, and their molecules will tend to rise into the air as soon as a bottle is opened.

When molecules of two kinds are present in a gas or solution, motion is impeded by the frequent collision of molecules, and the movement may be observed. This movement is called *diffusion.* One liquid may diffuse through another liquid. If a dense solution of potassium permanganate be placed at the bottom of a test tube of water, the red solution will be seen to diffuse through the water until the liquid is a uniform color throughout.

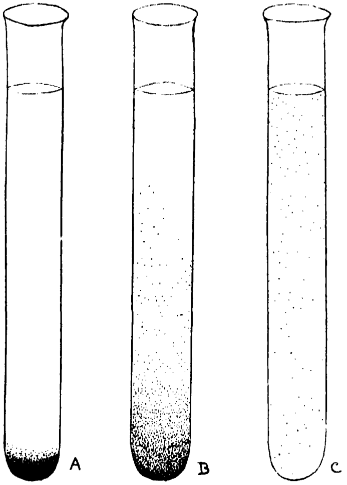

Fig. 22.—Diagram to illustrate the diffusion of a potassium permanganate solution through water contained in a test tube.

A solid may dissolve and diffuse through a liquid. A crystal of potassium permanganate placed in a small tube of water will dissolve slowly, and the dissolved molecules will diffuse through the solvent. A gas may diffuse through water as well as through air. Thus oxygen is available for respiration by aquatic animals and plants as well as terrestrial ones.

Osmotic Pressure.—Diffusion accounts for the movement of substances throughout the cell, but passage from cell to cell involves, in addition, hydration and osmotic pressure. If the molecules in diffusion come against an obstacle, they exert a pressure upon it. If the obstacle should be a *semipermeable* membrane, water will pass through the membrane until the pressure is equal on both sides. Living membranes differ from nonliving semipermeable membranes in that they are permeable to substances dissolved in water as well as to the water molecules. This is called *absorption.* Substances which will pass through such membranes are *crystalloids.* They include the sugars and salts, but some sugars, like cane sugar, may assume colloidal forms in solution and cannot pass through.

The osmotic pressure of any liquid will be proportional to the density of the liquid. This can be demonstrated by placing an animal membrane or a piece of parchment paper over a thistle tube, and clamping it firmly around the large mouth of the tube. The bulb is then filled with a cane sugar solution, and the tube is set in water with the bulb mouth wholly immersed in water. The sugar solution will absorb water and the pressure will force the liquid up the tube. When living cells imbibe water, they swell and pressure is exerted against the cell membrane. This causes a condition known as *turgor,* which maintains the shape of the cell. If water is withdrawn from the cell the protoplasm will shrink away from the cell wall, leaving a condition known as *plasmolysis.*

If there is no protective cell wall as in many animal cells, the plasma membrane may be too delicate to withstand unusual pressure. In the case of blood corpuscles, for instance, an excess of water will cause the cell to burst while withdrawal of water will cause shrinkage of the entire cell. (See Chapter XI for a fuller discussion of pressure.)

THE CELL

The cell is not only the unit of life—it is life itself, and within it take place all the complex functions of differentiation, of growth, and of multiplication.

Cells vary in size from the minute bacteria, of which six could be laid end to end across a human blood corpuscle, to the egg cells of birds, where the accumulation of yolk may make a cell (such as the ostrich egg) several inches in diameter.

They vary also in shape; a single nerve cell often attains a length of several feet, while epithelial cells are lined up like rows of bricks, and egg cells are characteristically round.

Max Schultze defined the cell as "a mass of protoplasm containing a nucleus," and this definition is in general use today, although it must be understood that the nucleus contains protoplasm also. It is customary, therefore, to designate the protoplasm outside the nucleus as the *cytoplasm;* that inside, the *nucleoplasm.* The two are separated by a delicate surface film, called the *nuclear membrane,* and the cytoplasm is also surrounded by a similar film, the *cell membrane.*

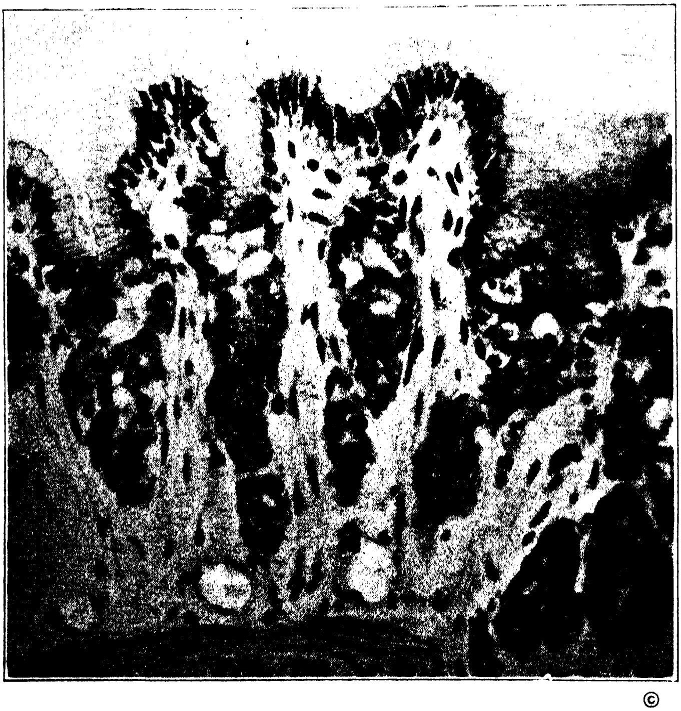
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Fig. 23.—Stomach of frog, showing simple columnar epithelium. (Photomicrograph from section by Albert E. Galigher.)

The presence of this membrane has been conclusively demonstrated by the microdissection experiments of Chambers. He finds that aqueous solutions, such as eosin, which do not penetrate into cells will diffuse readily through the protoplasm if injected through the membrane by means of a microscopically fine pipette. The plasma membrane, therefore, is not only pro-

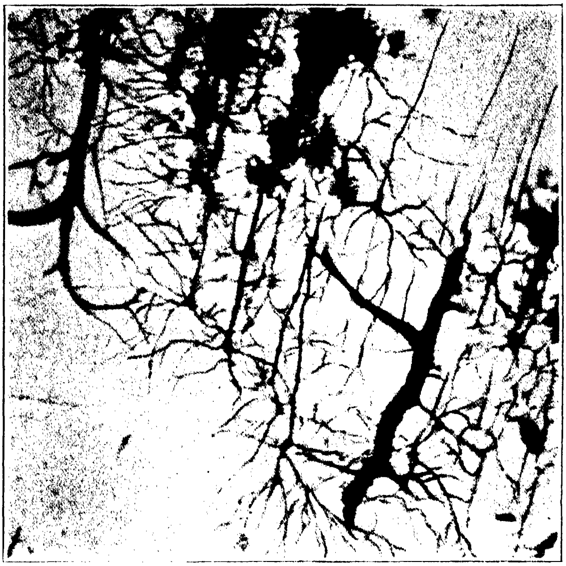

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Fig. 24.—Pyramidal nerve cells of the cerebral cortex, showing axones and dendrites. (Photomicrograph by Albert E. Galigher.)

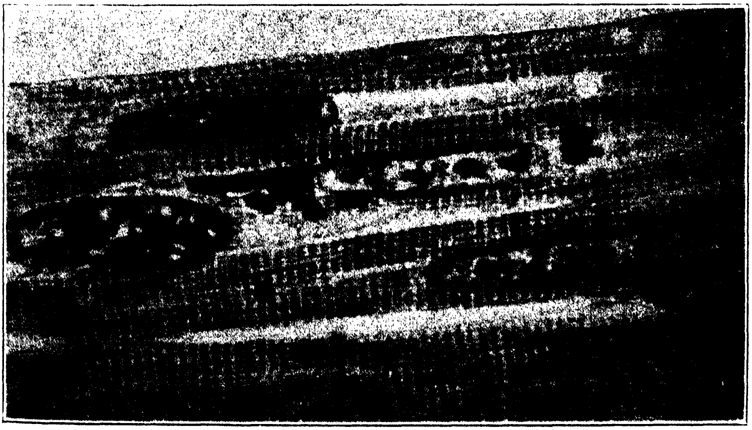

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Fig. 25.—Striated muscle fibers, showing striations and nuclei. (Photomicrograph from section of salamander muscle by Albert E. Galigher.)

tective but is responsible for maintaining the semipermeable properties of the cell.

The *true cell wall,* when present, is outside of this membrane and may contain secretions and precipitation products. In plant cells this wall is thicker and more conspicuous than in animal cells, in which it is often hardly discernible. The activity of plant cells for this reason does not involve the cell wall, and it is usual to speak of the living part of the cell as the *protoplast.*

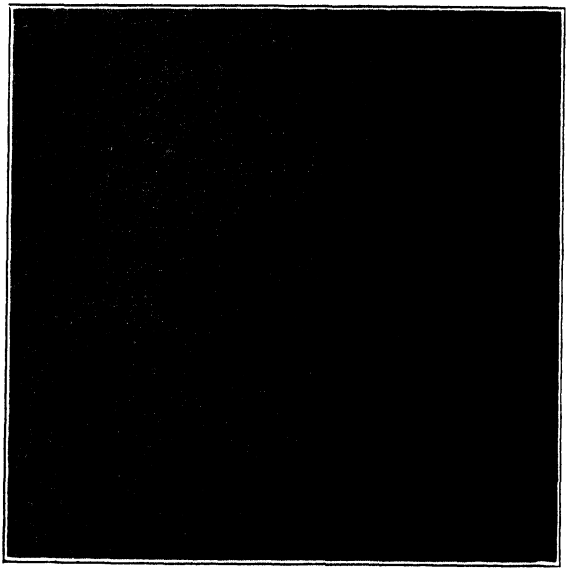

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Fig. 26.—Liver of salamander. (Photomicrograph from section by Albert E. Galigher.)

These walls are frequently crossed by fine strands of protoplasm, *the protoplasmic bridge,* which makes direct continuity from cell to cell.

The cytoplasm consists of a clear, homogeneous *hyaloplasm,* which forms the *external* or *continuous* phase of a colloidal system. In this hyaloplasm are suspended a variety of "formed bodies" or inclusions, which may be active, vital parts of the cell, or passive products of activity. These bodies constitute the *internal* phase of the colloidal system, which is the cell. They vary in size from the visible to the invisible, the ultramicroscope revealing still more and more minute particles until the limits of vision are reached. It is to be assumed, therefore, that still smaller granules would be disclosed could the vision be extended into the infinite.

This conception of the cell as a complex colloidal system was first suggested by Bütschli, and has recently been confirmed by the long series of experiments on living eggs and tissues, culminating in the microdissection experiments of Barber, McClendon, and Chambers which have made possible operations on the living cell, thus demonstrating its true nature. Such experiments have continually emphasized the cell as a colloidal system.

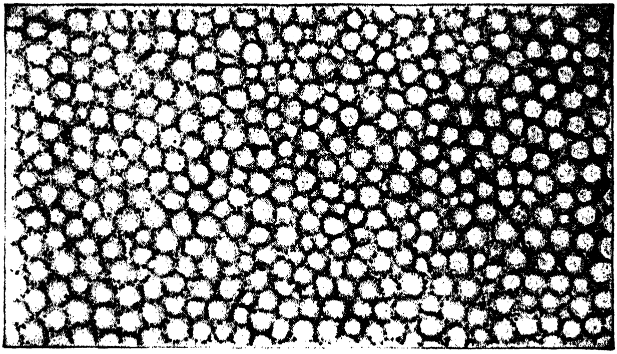

Fig. 27.—Structure of living protoplasm as seen in the starfish, showing macrosomes and microsomes. (Reprinted by permission from Wilson: The Cell. Published by The Macmillan Co.)

Formed Bodies

The Nucleus.—Most prominent among the formed bodies is the *nucleus.* It is typically round in form and is surrounded by a delicate plasma membrane. It contains one or more *nucleoli* suspended in a clear nuclear sap, or nucleoplasm. The nucleolus is believed to take an active part in the metabolic processes of the nucleus, possibly having a secretory function.

A nuclear framework usually exists in the resting nucleus, and if not visible, it can be made so by injuring the cell. Microdissection experiments show that injury makes visible bodies already present and accelerates the formation of those which would normally succeed them.

On this framework are scattered the chromatin granules which unite to form the chromosomes during mitosis.

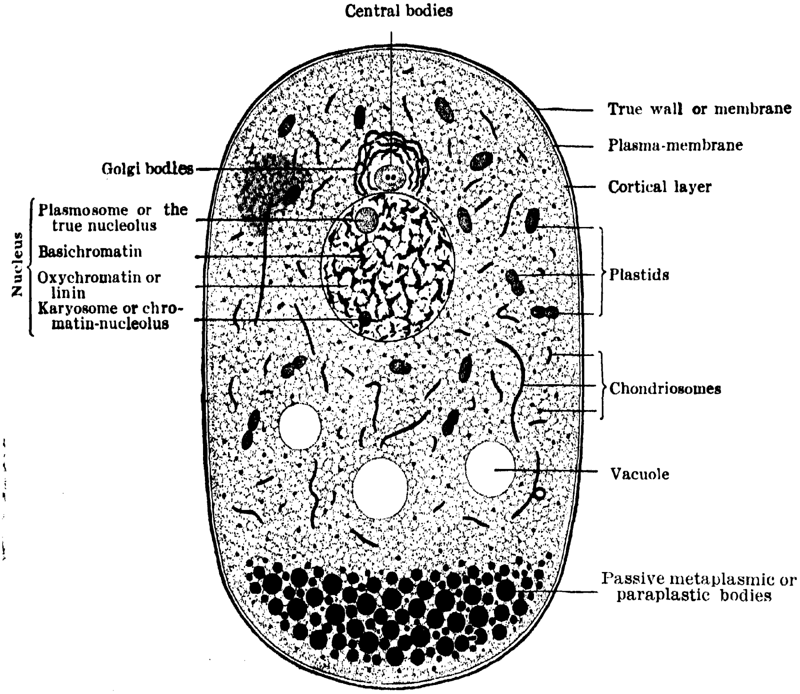

Fig. 28.—Diagram of a cell. (Reprinted by permission from Wilson: The Cell. Published by The Macmillan Co.)

DIVISION OF THE CELL

As early as 1855, Remak outlined a scheme of cell division very similar in gross details to division as known today as mitosis. It was not until 1858, however, that the significance of the process was recognized by Virchow as establishing genetic continuity from cell to cell. The full import of his aphorism "omnia cellulae e cellula" was not realized, however, until the pioneers in staining methods two decades later worked out a more delicate technique than had yet been known, and by which the real details of division became clear.

The process is primarily one of the nucleus, and the name karyokinesis applied by Schleicher is descriptive of this phase of the process. The name "mitosis" later applied by Flemming is now in more popular use. It applies to the so-called thread formation. Amitosis is used to designate division without the thread formation.

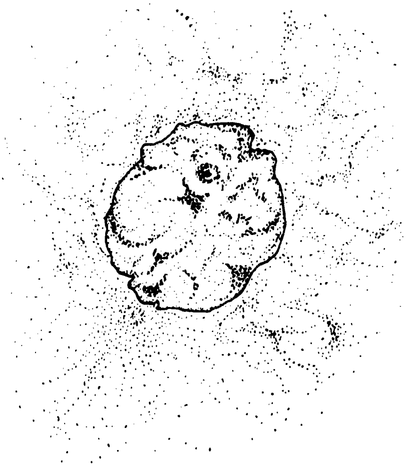

Fig. 29.—Resting stage in cell from the blastula of the whitefish *(Coregonus clupeiformis)*. Note centrosome with centriole at one pole. (Drawings by Elizabeth Kurtz.)

Mitosis is a progressive process, although it may be studied in stages which arbitrarily mark degrees of progress in the division. These stages are called the *prophase,* the *metaphase,* the *anaphase,* and the *telophase.* Each phase may be further subdivided into early and late phases. The division is preceded by a *resting stage.* It is only to the nucleus that the term "resting" can be applied, however, since the remainder of the cell is physiologically active all the time.

Two figures are formed during the process, the *chromatic figure* derived from the chromatin material of the nucleus, and the *achromatic figure* derived from cytoplasmic material. The latter figure forms the spindle-shaped structure to which the term "mitosis" applies. It is shaped like a double cone with two poles. At the poles are two attraction centers, the *centrosomes,* from which streams of cytoplasm radiate out to the equator, and about which similar streams may form starlike formations, known as the *asters.* The entire figure is then an *amphiaster.*

Not all animal cells form asters around the centrosome, and, in some, as in nearly all plant cells, the centrosome is entirely invisible. That it is characteristically present, even when ultramicroscopic, is probable, since when visible it is known to initiate the division process.

The structure of the achromatic figure has been the subject of much discussion. The fibers of the spindle are not threads as was first believed, but appear to be paths in the cytoplasm. That the figure has a greater viscosity than the surrounding cytoplasm has been proved by Chambers, who has been able to move the spindle about in the cytoplasm with his microdissecting needle. The paths probably have some relation to changes in electrical potential. The chromatin, being more acid than the rest of the cell, would be attracted to an electropositive region.

Details of Mitosis

This description is based upon division in the blastula of the whitefish. The blastula is an early stage in the development of the fish, and the cells are in rapid division. It is often possible, therefore, to find all stages of mitosis on one slide.

RESTING STAGE

The granules of chromatin material are scattered throughout the nucleus, held in suspension at the nodes of a very fine linin network. Outside the nucleus may be seen a *centrosome.* This appears as a clear area within which lies a minute, darkly-staining body, the *centriole.* Radiating out from the centrosome can be seen the *aster.* (Fig. 30.)

PROPHASE

During the prophase of mitosis the nucleus undergoes a marked change. The granules which have been scattered on the linin network are released, and are seen to be arranged serially in rows on long, thin threads. These threads can frequently be seen to be double, indicating a longitudinal division of the granular rows. Later, as the prophase proceeds, these

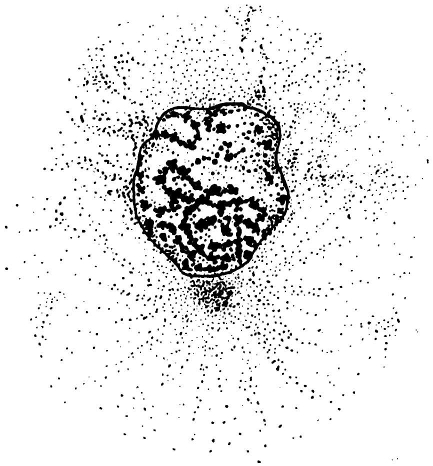

Fig. 30.—Early prophase. The chromatin granules are in linear arrangement on threads. Aster formation is in progress.

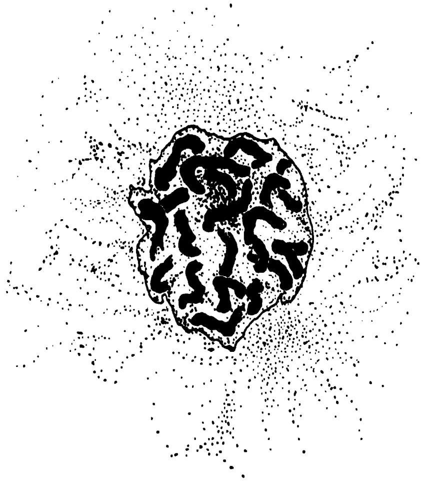

Fig. 31.—Late prophase. The chromatin thread has broken into chromosomes.

threads become shorter and thicker, and finally break into many separate pieces which become the characteristic chromosomes of the species.

The Chromatic Figure.—The *chromosomes* comprise the chromatic figure. They are often called the bearers of heredity, since they carry the *genes* which determine the hereditary characters of an individual. The number and size of the chromosomes will depend upon the species of animal or plant, and will never vary within the species. Any change in chro-

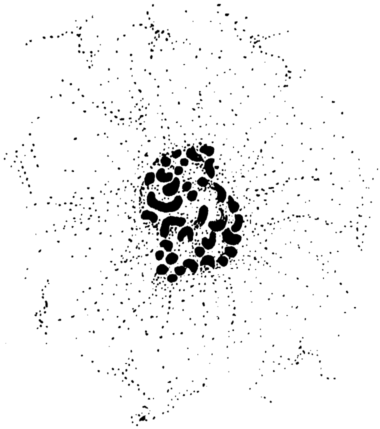

Fig. 32.—Polar view of a metaphase spindle showing the arrangement of the chromosomes on the equator of the spindle.

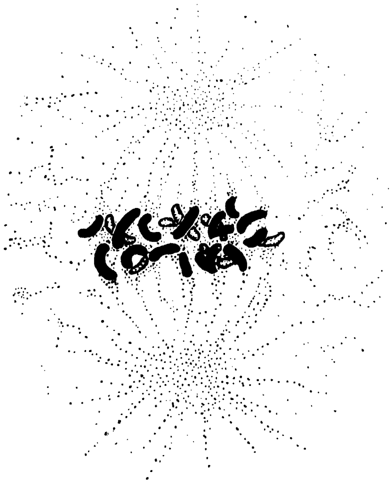

Fig. 33.—Metaphase. Note asters at the poles of the spindle. The chromosomes have divided longitudinally but are still on the equator of the spindle.

mosome number would indicate a change of species. In the whitefish, they can be seen to be numerous and rod-shaped. (Fig. 33.)

In spite of the apparently dissolute condition of the resting nucleus, the integrity of the chromosome is carried across from one cell division to the next, the same number of chromosomes of each particular shape appearing at the end of each prophase. It is probable that the granules which can be seen during the prophase are identical with those on the linin network of the resting stage. These are called *"chromomeres,"* and it is supposed that they carry one or more genes.

The Achromatic Figure.—Soon after the formation of the chromosomes, the centrosome divides and the two poles of the spindle are formed, with an aster about each centrosome. The fibers of the spindle appear almost immediately, and the chromosomes move on to the equator.

There are two sets of fibers, the *mantle* fibers, which recede as the chromosomes approach the poles, and the *interzonal* fibers, which remain behind and are often visible long after the cell division has been completed.

The figure in the whitefish is a typical *amphiaster* (Fig. 33).

METAPHASE

When the chromosomes are on the equator of the spindle, they are said to be in the metaphase (Fig. 33). Their attraction to the equator is probably determined by differences in electrical potential since the movement is rapid. Each chromosome at this stage is, in reality, a double rod, the split having passed longitudinally through the chromosome so as to divide each granule accurately into two equal halves.

The metaphase is of short duration, the attracting force which drew them onto the equator being almost instantly dispelled. The two halves of the chromosome spring apart as though activated by magnetism, and as they leave the equator the mantle fibers appear to shorten and precede them to the poles.

ANAPHASE

As the chromosomes gradually approach the poles, the interzonal fibers become more and more prominent, and there is a tendency for the mantle fibers to spread apart at the poles so that the spindle assumes a more or less barrel-shaped appearance.

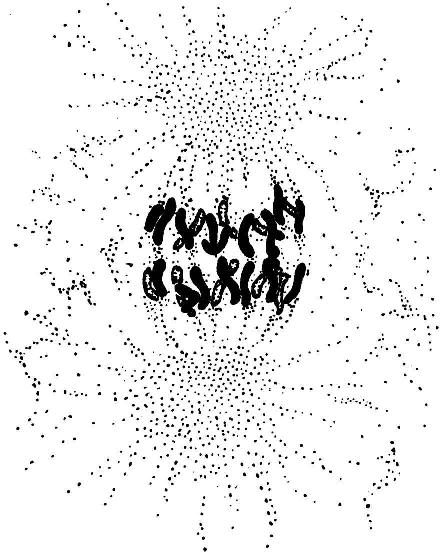

Fig. 34.—Early anaphase. Separation of the chromosomes.

TELOPHASE

The cell is in telophase as soon as the chromosomes reach the poles. A nuclear membrane forms around the chromosomes which contract up into a somewhat flattened nucleus. Inside the membrane they return to the granular condition by a reverse process which is very difficult to make out. The new cell is always somewhat flatter than the normal cell and the interzonal fibers may still be seen across the division plate (Fig. 37).

After division the cells quickly regain their normal shape and appear as resting cells. It is believed in the light of some recent experiments that the nucleolus performs the same function in the normal nucleus that the macronucleus does in Paramecium (see page 133) and is active in the metabolic functions

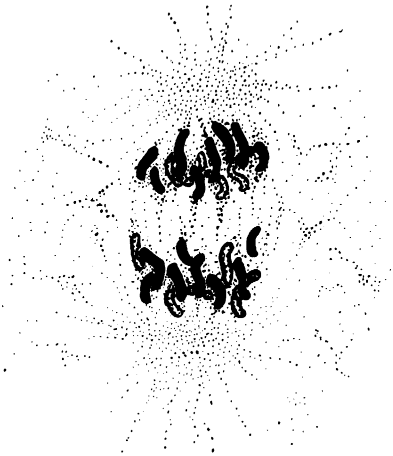

Fig. 35.—Late anaphase. The chromosomes have nearly reached the poles, and only the interzonal fibers of the spindle remain.

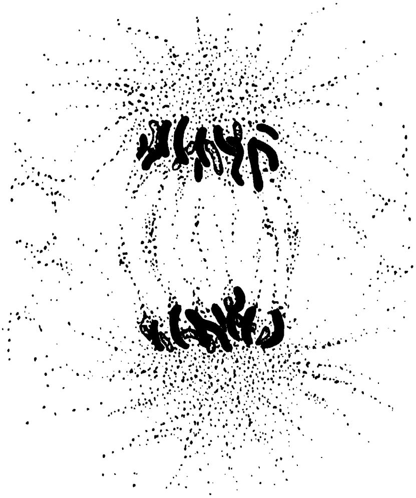

Fig. 36.—Early telophase. The chromosomes are at the poles.

of the cell. It disappears during division and a new nucleolus is formed in the nucleus of the new cell. In that case the chromatin material would correspond to the micronucleus of Paramecium, and any nucleus thus performs a double rôle. In Paramecium the two are separate and distinct so that the functions can be more easily demonstrated.

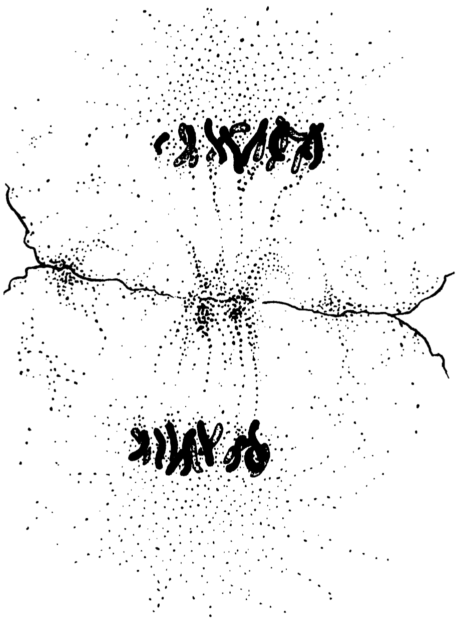

Fig. 37.—Late telophase. Division is now complete. The line of fission has cut through the equator of the spindle; the interzonal fibers are breaking up and the astral rays are dissipating.

Mitosis in the Onion Root

The process of mitosis in the plant cell is essentially the same, except that no centrosome can be seen, and, therefore, no aster. The cells of the onion root are rectangular in section, and the walls are flattened where they come in contact. The polarity of the spindle is less pronounced than in the animal cell, doubtless due to the absence of the attraction sphere; and the interzonal fibers of the spindle assume a characteristic barrel shape during the telophase, as the fibers do not bend in toward the poles.

The division plate appears first in the form of thickenings in the region of the equator. This becomes thicker and spreads out toward the periphery on all sides, eventually separating the cells. Thus, division in the plant cell starts from the center and cuts out, while in the animal cell, division starts on the periphery and cuts through.

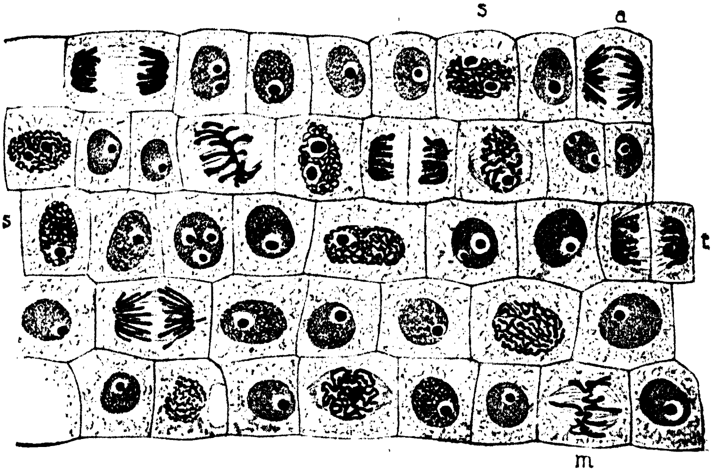

Fig. 38.—Mitosis as seen in the growing root tip of the onion. Several camera drawings have been combined to show all the stages of mitosis. *s*, Early prophase figures; *m*, metaphase; *a*, anaphase; *t*. early telophase. (Reprinted by permission from Wilson: The Cell. Published by The Macmillan Co.)

DIVISION BY AMITOSIS

Amitosis, as the name implies, is division without the aid of a spindle. The nucleus simply pinches in two as the macronucleus does in the division of Paramecium, and the division of the nucleolus precedes the division of the nucleus proper. In mitosis, a new nucleolus is formed.

This type of division is rare. It has been described in the cricket, in the follicle cells of the ovary, and is typical of all senescent cells.

SPONTANEOUS GENERATION

Prior to the nineteenth century belief in magic was widespread, and many myths existed regarding the origin of living things. Harvey, the physiologist of the early seventeenth century, was the first to recognize the development of life from the egg, and the aphorism, "omne vivum ex ovo" expressed his idea. He himself believed with his contemporaries, however, that the egg contained a miniature animal, as the seed contains a miniature plant, and that the egg could be spontaneously generated out of nonliving matter.

The small boy who throws a horsehair into the water, confidently expecting it to turn into a worm, is not more gullible than were many of the scientists of the Middle Ages. A common belief of the time was that a goose barnacle was a leaf come to life and destined to turn into a goose.

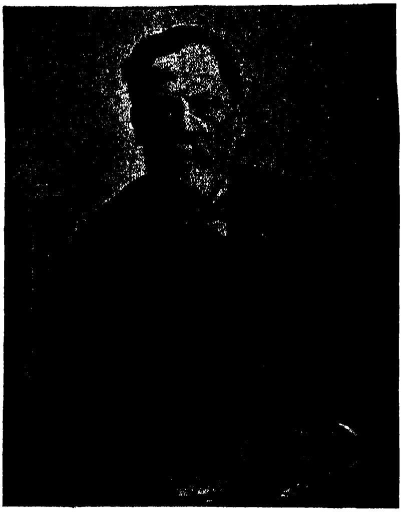

Fig. 39.—Louis Pasteur, 1822-1895. (From Garrison: History of Medicine. Published by W. B. Saunders Co.)

It was Louis Pasteur in 1861 who finally put an end to a long controversy on spontaneous generation, and established the now well-recognized truth that all life must come from preexisting life, "omne vivum ex vivo." Now that cell division has been established and the chromosomes have come to the foreground, the theory of genetic continuity is recognized not only of life and the cell, but also of the chromomere in the nucleus.

CHAPTER VI

THE GREEN PLANT

Life includes both plants and animals; therefore the plant must also be considered as a self-preserving and race-preserving system. In the animal, activity is necessitated by a varied and scattered food supply. In the plant, we shall find the very lack of visible activity to be an expression of the universal presence, not of the food, but of a fairly constant source of food supply; i.e., the sunlight, the atmosphere, and the soil. Water has been the most variable factor in the environment of the plant, so that water, more than any other single factor, has determined the character and distribution of the plants.

A WOODY PLANT

The highest type of plant structure is that of the seed plants. There are two great groups of these: the cone-bearing plants which are largely evergreen, and the flower-bearing plants the majority of which lose their leaves or die each season. The flower-bearing plants, *angiosperms,* include the greater part of the world's vegetation. There are woody and herbaceous types; the former including shrubs and trees, the latter the small flowering plants. They are divided into two groups: the *monocotyledons,* including lilies, palms, and orchids; and the *dicotyledons,* including violets, daisies, and roses. Often in the higher groups, the primitive woody structure is obscured by secondary tissues. The description which follows, therefore, refers to the lower groups when necessary to make the structure clear, and no single form or group is used.

Structure

We recognize in the higher plants four sets of organs: the *root, stem,* and foliage *leaves,* which care for the needs of the individual, and the *flower,* which is the reproductive organ.

These organs are made up of tissues which are continuous throughout the plant, and so form connected systems for the performance of the plant functions. Three primary tissue systems are recognized: the *epidermal* system, for protection; the *fundamental* system, for storage; and the *vascular* system, for conduction and support.

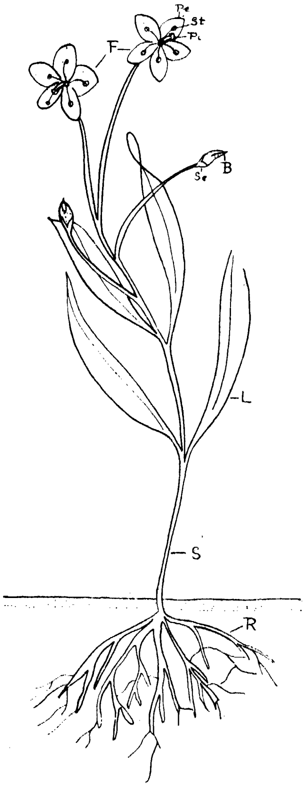

Fig. 40.—Diagram of a seed plant, showing roots below the ground, and stems, leaves, and flowers above. *R*, Root; *S*, stem; *L*, leaf; *F*, flower; *B*, bud; *Se*, sepal; *Pe*, petal; *St*, stamen; *Pi*, pistil.

The primary tissues develop from three primary growth tissues, the *meristems*, which, in turn, develop from an undifferentiated embryonic tissue, the *promeristem*. These tissues are to be found in the root, in the apex of the stem, and in the petiole of the leaf. The leaf blade has no meristem and is, therefore, a temporary structure which falls when heat and moisture fail. The meristems can be seen most diagrammatically in the root and will be described in that connection.

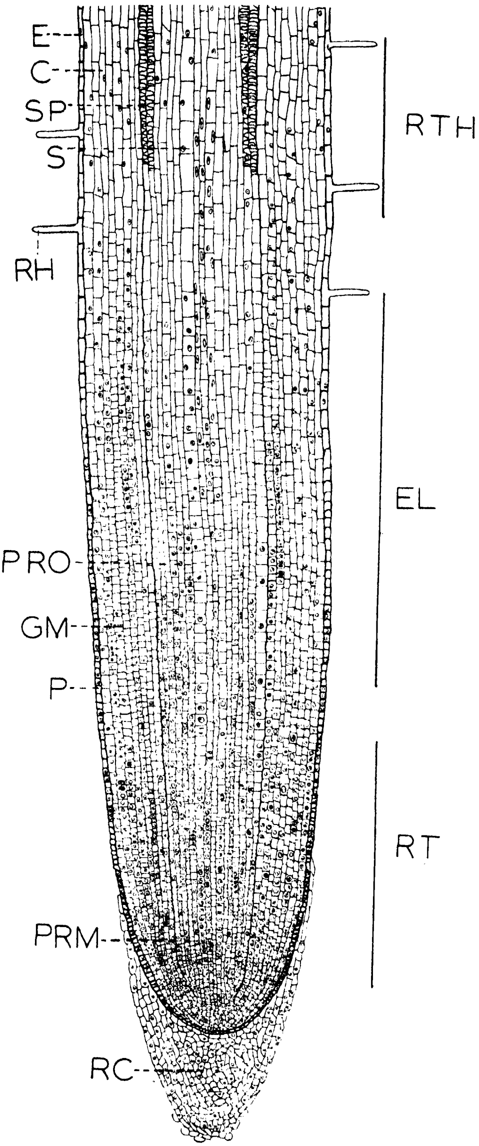

Fig. 41.—Root. Longitudinal section of the growing tip of the onion. *RT*, Region of root tip; *EL*, region of elongation; *RTH*, region of root hairs; *RC*, root cap; *PRM*, promeristem tissue; *P*, protoderm; *GM*, ground meristem; *PRO*, procambium; *RH*, root hair; *S*, stele; *SP*, spiral tracheid; *C*, cortex; *A*, epidermis.

Secondary tissues in the plant develop from the *cambium* which is itself a further development of the *procambium.*

ROOT

The root is a cylindrical structure found characteristically underground, although some plants develop aerial or aquatic roots. The first root to develop is the *primary* root. Branches of the primary root are *secondary* roots which may give rise to *tertiary* roots. This is the primary or *tap* root system. Other roots may develop, either replacing the primary root system or adding to it. If they replace it, they form a *fibrous* root system. Any roots of secondary origin are *adventitious.* They may develop from the stem or its branches, and, in rare cases, from leaves.

There are four regions in the primary root: the *root cap;* the *growing tip;* the *region of elongation;* and the *region of root hairs* (Fig. 41).

Differentiation is progressive upward. The root cap is inactive and is protective in function. The tip is the region of most active growth and is composed of undifferentiated *promeristem* cells. These are all alike and retain the potentiality typical of embryonic tissue.

In the region of elongation, differentiation into three types of generalized tissue takes place: the *protoderm;* the *ground meristem;* and the *procambium.* In cross-section, these show as three concentric circles, the protoderm on the outside.

In the region of root hairs, still further differentiation occurs. The protoderm has developed into an *epidermis;* the ground meristem into a *cortex;* and the procambium into a primary vascular tissue, the *stele.*

The root hairs are delicate and very numerous. They increase the absorptive surface, and thus bring the root into contact with a greater area of soil water.

Epidermis.—The epidermis of the root is not a true epidermis, since there is no protective cuticle. Only a thin plasma membrane separates the cells from the liquids in the soil. This facilitates absorption.

Cortex.—The cortex consists of fundamental tissue. It is sharply marked off from the stele by a layer of definitive cells, the *endodermis.* In the stem the endodermis disappears and fundamental tissue invades the stele.

Stele.—In the root the stele is typically composed of vascular tissue alone. The cells of this tissue form the conducting pathways for food and water, which are continuous from root to leaf. The heavy-walled xylem cells conduct water and contribute to the formation of wood; the thin-walled phloëm cells conduct food. The structure of this tissue will be found in the section on the stem.

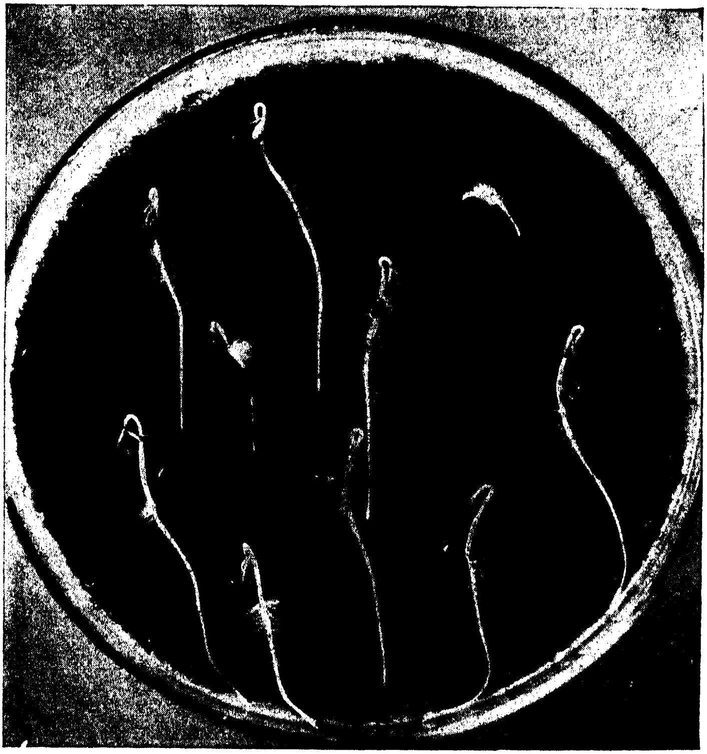

Fig. 42.—Germinating seeds of garden cress (Lepidium) grown in moist air. Note the dense growth of root hairs. (Reprinted by permission from Textbook of General Botany, by Holman and Robbins, published by John Wiley & Sons, Inc.)

The radial arrangement of the phloëm and xylem is characteristic of all roots. Clusters of xylem cells alternate with masses of phloëm so that they occupy different radii.

Pith is characteristically absent in roots, but appears in some of the more specialized types.

Three things serve to distinguish the root from all other organs of the plant.

1. *Root Cap.*—The cap of inactive cells is universally present in roots. It is only absent in such rare cases as the parasitic dodder, and some few degenerate plants infected with external fungous parasites. It thus serves to distinguish between the root and the stem, even when the root is aerial or the stem underground.

2. *Radial Organization.*—The arrangement of the phloëm and xylem in alternate radii is characteristic of roots in all phyla. Only in a few of the higher families does the secondary tissue invade the primary tissue and obscure the radial arrangement. Even in these groups, the primitive arrangement will prevail during development of the primary tissues. Thus the primary tissues of the roots link the higher plants with the earlier vascular plants. This is of the utmost importance in establishing relationships.

3. *Internal Origin.*—All secondary roots arise from the surface of the fibrovascular tissue well within the root. In stems the branches arise from cells close to the surface.

STEM

The stem is also typically cylindrical and usually grows upward, although horizontal underground stems, *rhizomes,* occur in some plants. Tubers, bulbs, runners, and other modifications of the stem also occur.

At the apex is the growing region protected by bud scales. Here is the promeristem which gives rise to the three primary meristems similar to those of the root. These, in turn, differentiate into the primary and permanent tissues of the stem.

Branches of the stem arise at the surface in the axiles of the leaves.

The stem has three main areas, the *epidermis,* the *cortex,* and the *stele.* The stele contains an outer *pericycle,* a cylinder of vascular tissue, and an inner *pith.* The pericycle and pith cells are composed of fundamental tissues which have invaded the stele so that the primitive arrangement of the root is obscured.

Epidermis.—The epidermis, derived from the protoderm, is a single layer of vertically elongated cells, the outer walls of which are thickened into a *cuticle,* so called because it contains a waxy substance, *cutin,* which is impermeable to water.

On the epidermis are found the leaf scars which mark the insertions of former leaves. These mark the nodes of the stem, the intervening regions being internodes. On the epidermis are a few scattered openings, the stomata, which will be described in connection with the leaf.

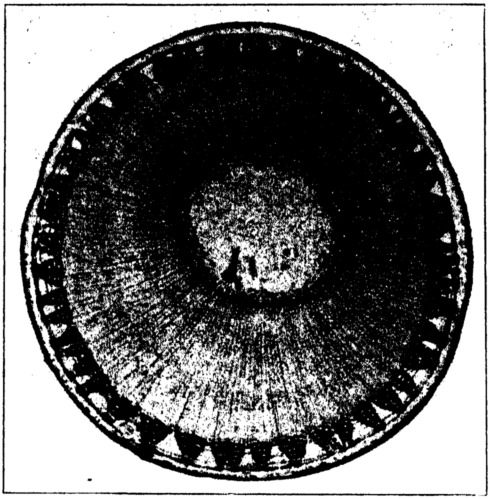

Fig. 43.—Dicotyledon. Cross-section of the stem of the basswood, Tilia.

Cortex.—The cortex usually contains several types of fundamental tissue. Just beneath the epidermis is the *collenchyma,* a tissue in which the cell walls are thickened at the corners to give mechanical support. Usually living *plastids,* such as *chloroplasts,* are present and retain life over a long period. The cells containing chloroplasts are distinguished as *chlorenchyma,* since in them are formed the *chlorophyll* which give the green color to plants.

In older stems, some of the collenchyma may develop into a *cork cambium,* forming a ring of dividing cells under the epidermis. These cells give rise to cork on the outside and to *parenchyma* on the inside. The cork may entirely replace the

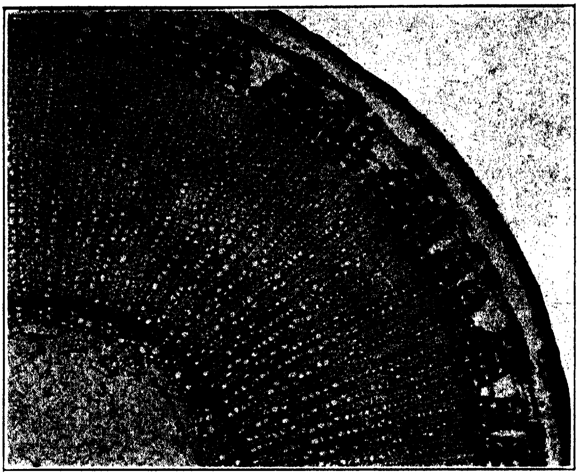

Fig. 44.—Dicotyledon, sector of the stem of the basswood, Tilia. Enlargement of a portion from previous figure.

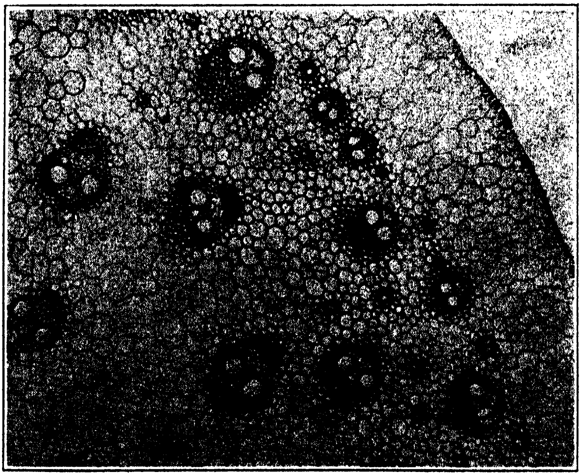

Fig. 45.—Monocotyledon, sector of the corn stem.

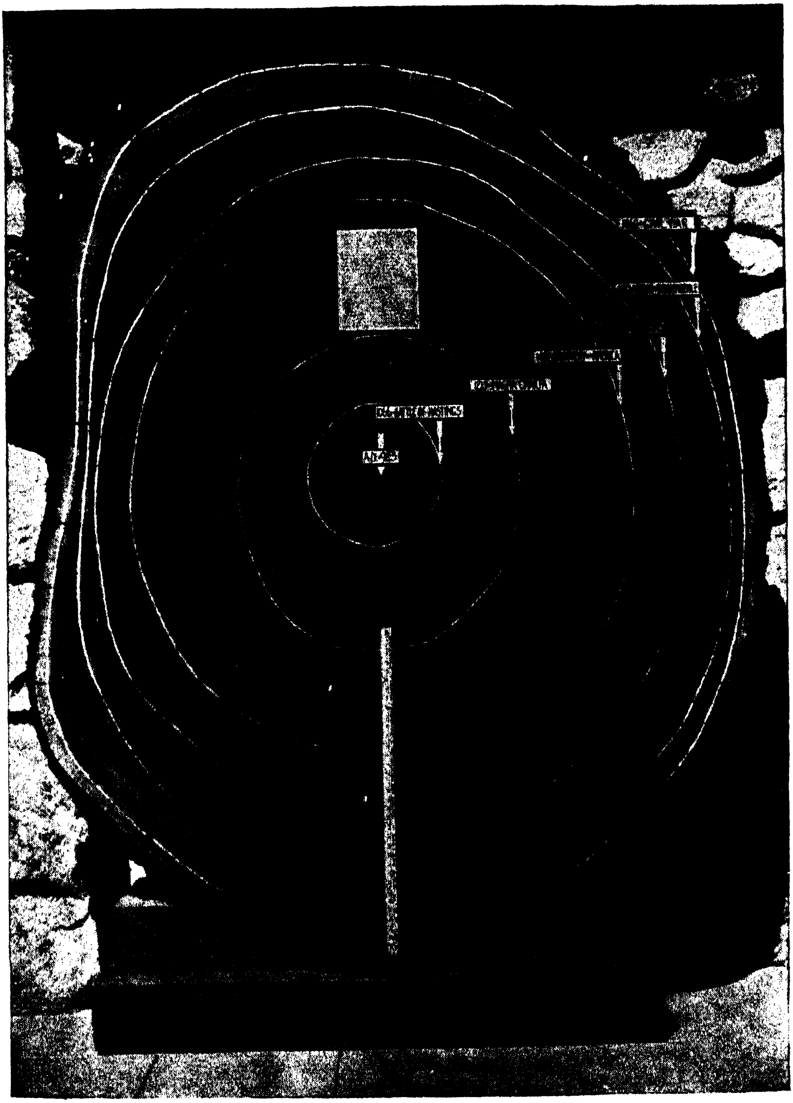

Fig. 46.—A cross-section of a relatively young tree of *Sequoia gigantea*. The chalk lines and arrows, except the central one, indicate approximately the annual rings formed in the years during which a number of events of historic importance took place. The tree began its growth about A.D. 923, and was about one thousand years old when cut. (Reprinted by permission from Textbook of General Botany, by Holman and Robbins, published by John Wiley & Sons, Inc.)

epidermis in which case the stomata are replaced by *lenticels,* areas of loose tissue through which communication is established between the internal atmosphere of the intercellular spaces and the external atmosphere.

Beneath the collenchyma is an extensive layer of thin-walled *parenchyma* cells. This is the most characteristic of the fundamental tissues. They frequently contain vacuoles and are loosely grouped so that intercellular spaces occur.

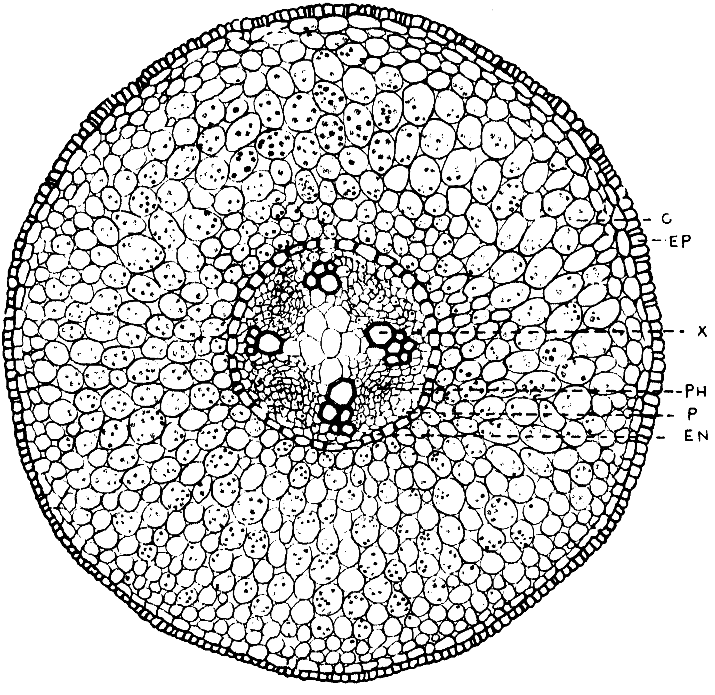

Fig. 47.—Root. Cross-section of root of crowfoot, *Ranunculus acris,* through the region of root hairs. *C,* Cortex; *EP,* epidermis; *X,* xylem; *PH,* phloëm; *P,* pericycle; *EN,* endodermis. Drawn by Frances Fiske.

Certain specialized cells of the cortex have greatly thickened walls which almost eliminate the cavity. Before the death of the cells, the walls become impregnated with *lignin,* a substance which greatly strengthens the stem.

These cells are of two types, *bast fibers* and *stone cells.* The fibers are elongated cells pointed at both ends. They are frequently elastic. Stone cells are shorter and are not elastic.

Most of the textiles, such as linen, are made from materials consisting almost entirely of bast fibers, while the shells of nuts are composed almost entirely of stone cells.

In the stems of herbaceous plants, the endodermis still separates the cortex from the stele, but in the woody plant, the cortex of the stem merges with the cells of the pericycle.

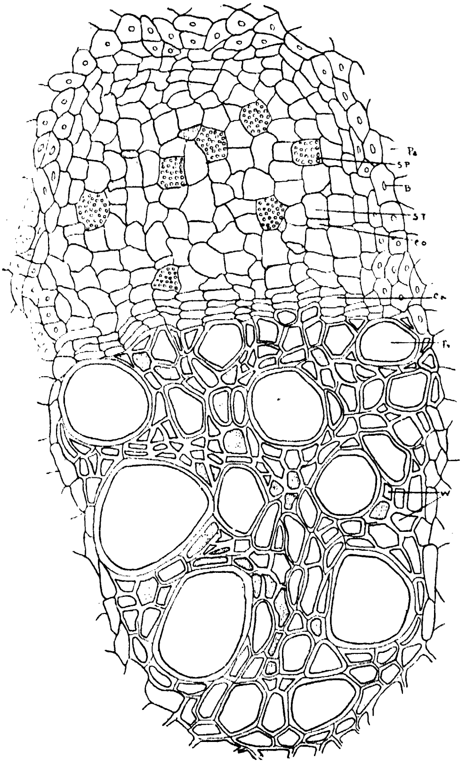

Fig. 48.—Vascular bundle of a dicotyledon. *Pa,* Parenchyma; *B,* bast fibers; *S.T.,* sieve tubes; *S.P.,* sieve plates; *Co,* companion cells; *Ca,* cambium; *Tr,* tracheal tubes; *W,* wood cells. (Drawn from the stem of the clematis by Florence A. Basehoar.)

Stele.—The cells of the pericycle and pith are cells of the fundamental tissue from the ground meristem. They are of the parenchyma type. In the pericycle, there may be chloroplasts and fibers in the cells; in the pith, the cells grow larger and are used for storage. There are numerous intercellular air spaces which form a part of the general aerating system of the plant.

Pith rays of parenchyma cells may extend out to the pericycle and lengthwise between the nodes. The height of the rays will depend upon the length of the internodes, and may vary from the length of a few cells to several centimeters. Both the pericycle and the pith owe their origin to the fundamental tissues of the stem and are not a part of the vascular system.

Vascular Bundle.—Between the pericycle and the pith are the *vascular bundles,* and in the dicotyledons these are arranged in a ring around the stem. The procambium differentiates into primary *phloëm* cells on the outer side and primary *xylem* cells on the inner side.

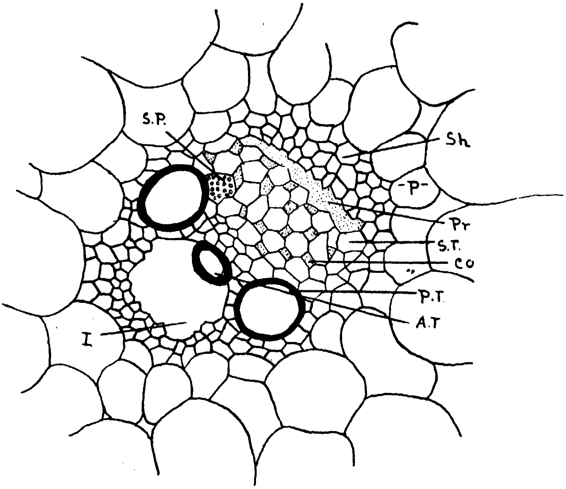

Fig. 49.—Vascular bundle of a monocotyledon. *P,* Pith cells; *Sh,* bundle sheath; *S.T.*, sieve tubes; *S.P.*, sieve plate; *Pr,* protophloëm; *Co,* companion cell; *P.T.*, pitted tracheal tube; *A.T.*, annular tracheal tube; *I,* intercellular air space. (Drawn from a photograph of the corn stem, by Florence A. Basehoar.)

A permanent layer of growing tissue often persists after the differentiation of the procambium. The cells are thin-walled and flattened. These are the *cambium* cells; they contain living protoplasts and continue to give rise to phloëm and xylem cells indefinitely. Thus the stem increases in girth from year to year.

Cambium cells may also contribute to the pith rays, and additional vascular rays may be produced. The vascular rays never extend to the pith, but together with the pith rays they form what are frequently called medullary rays. These provide for the transverse distribution of liquids.

All tissues derived from the cambium are secondary.

Phloëm.—The phloëm is essentially a food-conducting tissue consisting of *sieve tubes, companion cells,* and phloëm parenchyma. Phloëm fibers are also frequently present.

Sieve tubes are made up of elongated cells placed end to end and perforated at the thickened end. It is through these perforations that the protoplasm carries food from cell to cell. A row of companion cells accompanies each sieve tube, and assists in some way the functions of the sieve tubes. The parenchyma cells may also serve in the conduction of foods.

Xylem.—The xylem is the woody part of the stem. Four types of cells form in the primary xylem: vessels, tracheids, woody parenchyma, and wood fibers.

Summary of the Tissues of the Stem*

	Primary meristems		Primary permanent tissue		
Promeristem	Protoderm		Epidermis		
	Ground meristem	Cortex	Collenchyma (chlorenchyma) Parenchyma Endodermis, if present		
		Pericycle	Parenchyma fibers		Stele
		Pith rays			
		Pith			
	Procambium	Primary phloëm	Parenchyma Sieve tubes Companion cells Fibers	Vasc. bundle	
		Cambium	Secondary phloëm Secondary xylem Vascular rays		
		Primary xylem	Tracheal tubes Tracheids Woody parenchyma Wood fibers		

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Vessels.—The vessels are formed from whole rows of elongating cells by dissolution of the end walls. The protoplasts die and the walls thicken in patterns. The thinner areas allow for absorption and the thicker areas prevent collapse of the wall. Sometimes cellulose is formed in the thickenings; sometimes they are lignified.

In the elongating region of the root, the thickenings are either angular or spiral, but in cells which have ceased to elongate, the reticulate or pitted condition may arise. *Pits* are characteristic of the higher plants, and may be either simple or bordered, according to the presence or absence of an overarching margin to the pit.

Tracheids.—Tracheids are simple elongated cells narrowed at the ends. The walls are thick and lignified and usually have bordered pits.

Parenchyma.—The *woody parenchyma* consists of short, thin-walled cells which do not die as quickly as the other xylem cells. Their function is the storage of water and food, although they may also aid in conduction for short distances.

Fibers.—*Wood fibers* are longer and have thicker walls than the parenchyma cells, so are better suited for strengthening but less fitted for water conduction than are the tracheids.

Secondary Tissues.—In woody plants secondary phloëm and xylem growths occur. The procambium gives rise to a permanent cambium which continues to produce phloëm outwardly and xylem inwardly throughout the length of the plant.

The primary growth is upward, but the secondary growth is outward, increasing the girth of the stem. This is increased by additional growth from a cork cambium, a ring of meristem cells just under the epidermis. These cells divide much as the cambium cells, giving rise to cork on the outside and to secondary cortex cells on the inside. When the cork cells die, they cut off the epidermal cells from food and water, and these cells die leaving the cork on the surface. The secondary cortex cells on the inside may remain alive for a long time. They form a secondary tissue called *phelloderm.*

As the width of the stem increases, the active phloëm cells are farther from the water conducting cells, and vascular rays are produced by the cambium. These permit radial conduction and facilitate the passage of materials through the thickened stem.

Wood.—The main woody tissue of the plant is from the xylem. Wood is formed by the lignified walls of dead xylem cells. In regions where a season of active growth alternates with a season of inactivity, *annual rings* will be formed marking each season's growth (Fig. 46), thus making it possible to determine the age of a tree by counting its annual rings.

LEAF

The leaves are the most abundant of plant organs. Collectively they make up the foliage of the plant and are characteristically green. Since the corolla of the flower is composed of specialized leaves, it is customary to speak of the green leaves as the foliage leaves. Usually they are composed of *blade, petiole,* and *stipules,* but any one of these may be lacking. When the petiole is lacking, the leaf is said to be sessile; when present, it is a narrow, cylindrical structure, and is the region of rapid growth. Stipules are usually paired structures at opposite sides of the base of the petiole. They may form tendrils which cling to surfaces, or they may be bladelike, or they may form spines. When spiny, they have a protective function.

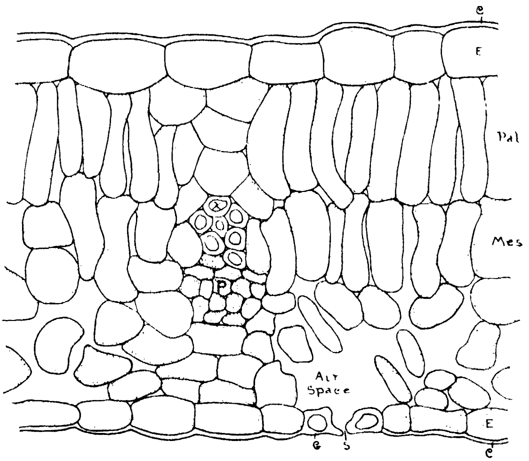

Fig. 50.—Section of a lilac leaf. *C*, Cuticle; *E*, epidermis; *Pal*, palisade cells; *Mes*, mesophyll; *X*, xylem; *P*, phloëm; *G*, guard cell; *S*, stoma. (Drawn from a slide.)

The main expanse of the leaf is the *blade,* which may take many forms. In the *axil* of the leaf is found the *bud* of a new branch, for the leaf, being but a temporary structure, susceptible to temperature changes, drops off in the fall. The bud, however, is very resistant, usually remaining unharmed through all the vicissitudes of winter. When the sap starts to flow in the spring, however, the young leaves bursting forth are more than ever susceptible, and are frequently injured by frost.

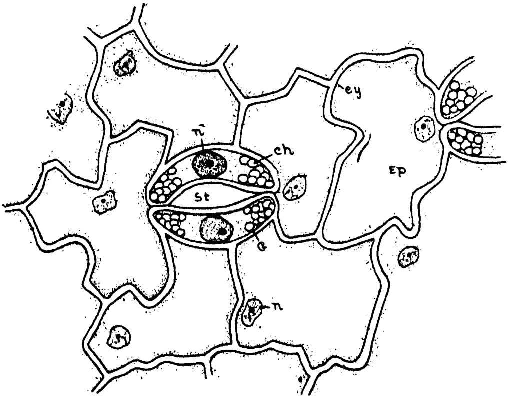

Fig. 51.

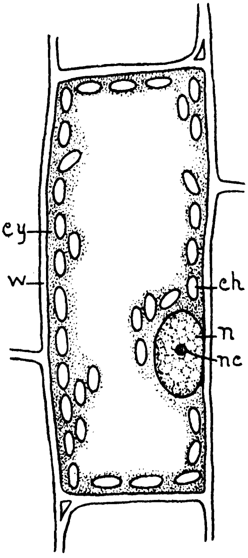

Fig. 52.

Fig. 51.—A portion of the lower epidermis of a leaf. *n,* Nucleus; *ch,* chloroplast; *g,* guard cell; *st,* stoma; *ep,* an epidermal cell; *cy,* cytoplasm. (Drawn from a leaf of the privet. The nuclei were made visible by formaldehyde.)

Fig. 52.—Palisade cell from leaf of clematis, magnified. *cy,* Cytoplasm; *w,* cell wall; *ch,* chloroplast; *n,* nucleus; *nc,* nucleolus.

The growing cells of the leaf are in the *petiole.* They give rise to the three main tissues: the epidermal tissue, or *epidermis;* the fundamental tissues, *the mesophyll;* and the *vascular tissue* in the bundles. These tissues are continuous with similar tissues of the root and the stem and, therefore, complete the pathways from the root to the leaf.

Epidermis.—The epidermis covers the entire blade and may be *waxy, hairy,* or otherwise modified for protection.

Mesophyll.—The spongy tissue which fills the fleshy portion of the leaf is the mesophyll. It is the fundamental tissue and is continuous with the cortex of the stem. It contains many *chloroplasts.* Just under the epidermis the cells are usually arranged in a close series, and are called *palisade* cells. This is the surface most persistently turned toward the sun.

Below this layer the cells are more loosely arranged, and many *air spaces* occur between them which communicate through the stomata with the external atmosphere, and are continuous with the air spaces in the stem.

Vascular Bundles.—The bundles of the leaf are continuous with those of the stem and complete the pathways for food and water. They appear on the surface as the veins of the leaf and have a characteristic arrangement. In the monocotyledons the veins are parallel in arrangement, and in the dicotyledons they are branched to form networks.

Flower

The flower is an organ of reproduction and plays no part in the vegetative functions of the plant. It is borne on a stem, the *peduncle,* the apex of which is flattened and broadened to form a *receptacle.* This serves as an axis on which specialized leaves are arranged in whorls or spirals. These leaves have lost all resemblance to foliage leaves and are called *floral leaves.* The outer whorls are showy and aid in attracting insects. Insects carry the pollen from one plant to another on their legs. When they light on a flower with pollen-laden legs, the sticky surface of the pistil rubs off the pollen and thus cross-pollination is accomplished.

Cross-pollination is sometimes brought about by the wind, but the flower is especially adapted to insect pollination. A few plants may use the pollen from the same plant, in which case they have self-pollination.

There may be four or five whorls of floral leaves. The two outer ones form collectively the *perianth* which serves as a protective envelope about the inner whorls.

Perianth.—The outer whorl of the perianth is the *calyx,* the separate leaves of which are the *sepals.* These often retain the green color and the leaflike structure. The inner whorl is the *corolla,* composed of *petals* which are sometimes separate, but often fused. In most cases these form the most conspicuous part of the flower and are often highly colored. They frequently aid in attracting insects, which carry the pollen from plant to plant.

Inside the perianth the whorls are made up of specialized leaves which directly produce the reproductive cells (male and female gametes). The outer whorls are composed of stamens; the inner whorl is composed of carpels.

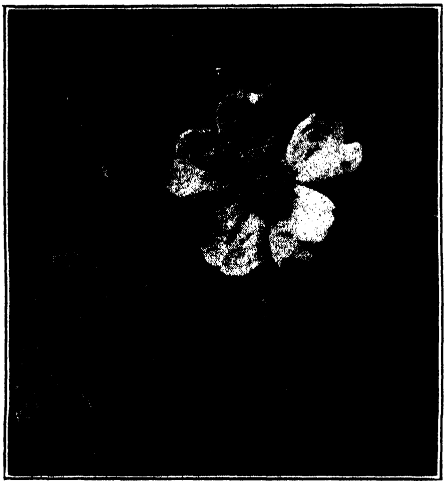

Fig. 53.—*Rosa virginiana,* the pasture rose. (Photo by Clyde Fisher. Courtesy of the American Museum of Natural History.)

Stamens.—Each stamen consists of a slender filament, at the end of which is the *anther.* In the blade are found the pollen sacs, inside which the pollen grains are produced.

Pistil.—At the apex of the receptacle is the *pistil.* Each leaf of the pistil is a carpel, and the pistil will be simple or compound depending upon whether it is formed from one or more of the carpels.

The pistil is composed of three parts: the *ovary, style,* and *stigma.*

Style.—The style is a long column of tissue extending from the top of the ovary.

Stigma.—The stigma is the expanded upper end of the pistil. It frequently has a rough, sticky surface which serves to catch and hold the pollen grains. From a pollen grain a *pollen tube* will grow down the style to the ovary.

Ovary.—The ovary is the rounded basal portion of the pistil, within which one or more *ovules* are formed. Each ovule is attached to a placenta by a stalk, or *funiculus*. The placenta sometimes marks the line of fusion between the edges of the carpels, so that the number of placentas in an ovary often indicates the number of carpels involved in its formation.

Ovule.—Each ovule develops as a protuberance of growing cells, the *nucellus*. This tissue develops two layers of protective tissue, the *integuments*, which grow about the nucellus so as to leave a minute opening, the *micropyle*, through which the pollen tube can enter.

In the nucellus there also develops an *embryo sac* in which the gamete will form for union with the male gamete. There are no cell walls formed between nuclei so that the *egg nucleus*, which is the female gamete, is only one of eight nuclei.

The pollen tube grows into the embryo sac through the micropyle. It contains two *sperm nuclei*, one of which will unite with the egg nucleus to form the *zygote*. The other sperm nucleus will unite with a *fusion nucleus* which has been formed by the union of two nuclei of the embryo sac. This fusion forms the *endosperm nucleus* which develops the nutritive tissue for the developing embryo.

The fruit of the plant is developed from the ovary, and the seed from the ovule, the integuments persisting as the seed coats.

Seed.—The seed when ripe will contain the endosperm and a minute rudimentary plant. This consists of a tiny stem, the *hypocotyl;* a root, the *radicle;* a minute bud, the *plumule;* and the seed leaves, the *cotyledons*. The endosperm may, or may not, be absorbed into the cotyledons.

Germination

Germination usually occurs on planting the seed. The seed absorbs moisture in the presence of the optimum temperature, and the little embryo begins to grow. The seedling will live on the endosperm tissue until the leaves have expanded sufficiently to allow photosynthesis to take place.

CHAPTER VII

THE LIVING PLANT

The functions of self-preservation in the green plant are much the same as those in the animal except that the plant has the additional power of manufacturing its food and thus avoids the need to capture it. Food requirements are the same. Proteins, fats, and carbohydrates and the same inorganic salts are needed for the metabolic activities, but since the plants cannot ingest them in that form, they take the raw materials from the air and from the soil and build them into organic molecules.

The process of photosynthesis by which the green plant synthesizes its food is the reverse of respiration and completes the cycle which was incomplete in the grasshopper's metabolism. The energy for the process comes from the light rays. The energy for all other metabolic processes is released from the food by the oxidation process.

BEHAVIOR

Since the raw materials needed by the green plant are found in the carbon dioxide in the air and in the salts in solution in the water of the soil, the ceaseless activity of the animal is absent; yet roots often grow long distances to reach water, and leaves turn persistently to face the light. The plant has a behavior, therefore, which is the sum total of its reactions. These reactions are expressed in tropisms which are adaptive, since they tend to bring the plant organs into the most favorable position for procuring the necessary raw materials.

Tropisms require irritable tissues to receive the stimulus from the external environment, some means of conducting the stimulus to the point of response, and a means of responding to the stimulus. When a green plant is moved to a window from a previously darkened room, within twenty-four hours a curvature will be noted in the stems and in the petioles of the leaves. Not all the leaves will have completed the turn, for the responses are slow, but all will show some curvature in the direction of the light. This is a positive *phototròpism.* It fulfills all the requisites of a tropism as to irritability, conduction, and response. To show how this is accomplished, we must first consider the *phytohormones,* the chemical coordinators of the plant kingdom.

Phytohormones.—Three of these phytohormones have been isolated. They are commonly referred to as *growth hormones* since they stimulate cell elongation. They have a much wider significance, however, than the term growth hormone infers, for chemical coordination is considered more primitive than nervous coordination in the organic world, and there has been a close correlation between the development of the nerves in animals and the chemical hormones. The same correlation between the chemical and the electrical method of conducting stimuli will be seen to exist in the plant kingdom. (See Chapter XII for details.)

The hormones known are called *auxins.* Chemically, only one is a protein derivative. This is *heteroauxin,* a 3-indole acetic acid. Heteroauxin is not found in the higher plants but is found in the bacteria and in certain of the fungi (Rhizopus and Aspergillus). This may indicate that the heteroauxin is the primitive type of hormone molecule in plants.

All auxins have the same effect on plant cells so are not specific. This can be proved by the use of small gelatin blocks. When such a block is placed against a root tip, the cells of which are negatively phototropic, some of the hormones will diffuse out into the gelatin block. By placing this block against one side of a seedling tip, curvatiure of the tip follows. As the seedling tip is positively phototropic, it is apparent that cell elongation is stimulated whatever the stimulus. The experiment can be done conversely by exposing the seedling tips to light and allowing the hormones to diffuse into the gelatin. This gelatin block stimulates curvature in the root tips.

The normal reaction of stems and leaf petioles to light is positive; of root tips, negative. If the effect of the hormone is to cause curvature in either case, one may well question how the reverse response in roots is accomplished. It has been found that the amount of concentration of the hormones is the answer. In excess concentrations the hormones will inhibit rather than stimulate growth. In the roots the hormones collect in concentrations higher than in the stems and so inhibit the response of the root cells. This makes the root tips negatively phototropic.

Although the auxins show no specificity, they differ in their molecular structure and in their reactions to acids and alkalies. As the acid-base concentrations in cells account for the bioelectric currents there, these reactions are important (see Chapter XI).

Auxin A ($C_{18}H_{34}O_5$) is stable in acid, but sensitive to alkalies. It is the commonest hormone in the higher plants.

Auxin B ($C_{18}H_{30}O_4$) is destroyed by both acids and alkalies. It is also found in the higher plants.

Heteroauxin ($C_{10}H_9O_2N$) is sensitive to acids but stable in alkalies. It is found only in bacteria and in certain fungi.

Auxins can be spread through the plant in four ways:

1. By diffusion
2. By protoplasmic streaming
3. Through the circulatory pathways of the plant
4. By electric phenomena

Irritability.—The meristem tissues of green plants are irritable. They are found in the root tip, in the apex of the stem, and in the petiole of the leaf. In Chapter XI irritability is shown to be a function of the plasma membrane of the cell, and stimulation is shown to cause a change in permeability of the plasma membrane. This change in permeability means that chemicals to which the membrane is normally impermeable may slip through when it is stimulated. This may account for the movement of hormones in response to stimulation.

Conduction.—Normally the region just outside a cell is electropositive to an electronegative interior. On stimulation bioelectric currents are set up. It has been found that when a stem is stimulated by light, the cells on the shaded side become electropositive to the lighted area. Thus a polarity is set up across the cell, and since the electropositive area will be an area of greater acidity due to the concentration of the hydrogen ions, the reactions of the auxins to acids and bases are of importance. Auxin A which is stable in acids but sensitive to alkalies will move from the alkaline electronegative area to the more acid electropositive area. The greater permeability of the plasma membranes facilitates the passage of the hormones across the stem.

Response.—The response of plant cells to any stimulus is always elongation. If this elongation is equal on all sides, growth will be straight up or down. When elongation is on one side only, curvatures result. The concentration of hormones on the darkened side of a stem stimulates the cells on that side to elongate in the direction of the long axis. Elongation of cells on the darkened side will cause the stem to curve toward the lighted side. Thus the response is a positive one with relation to the stimulus—a positive *phototropism.*

The response is necessarily slow. There is a long latent period between stimulus and response while the hormones are moving across the stem. And since all response is by cell elongation, and this is a matter of cell growth, it may take several days to accomplish a complete turn. Cell elongation occurs faster at night when the stimulus has been withdrawn. This makes it more difficult to see the relation between stimulus and response. Nevertheless, the tropism is complete, and the electric phenomena which facilitate the movement of hormones across the stem make clear the close correlation between chemical and neural functions.

Since the functions of nerves in animals have long been known to involve electric phenomena, it is not strange that scientists are beginning to look on the electric changes in plant cells as a type of nervous activity. Bose, the Indian scientist, and some of his followers claim to have demonstrated a simple nervous mechanism in some of the higher plants. It is certain in any case that coordination of plant activities is accomplished and that this may not be entirely a chemical coordination.

There are a few plants in which responses to touch follow on such rapid turgor changes that the reactions are immediate. In the sensitive plant, *Mimosa pudica,* the leaf will fold up if touched on a warm day, and the leaf blades of a Venus flytrap, *Dionaea,* will snap over an unwary insect when it walks over the bristles on the margin of the blade. In the sundew, *Drosera,* the insect touching the glandular hairs on the leaf causes the same effect.

In Mimosa there is a thickened portion of the petiole called a *pulvinus* which is composed almost entirely of parenchyma cells. The arrangement of the cells is such that water passes into or out of the pulvinus more freely on one side than on the other. The unequal movements of the water accounts for the movements of the attached leaf blade. There is first a lifting of the leaflets, then a gradual closure of the branch petioles, and finally a downward movement of the main petiole. The petiole is actually forced downward by the change in the size of the pulvinus cells.

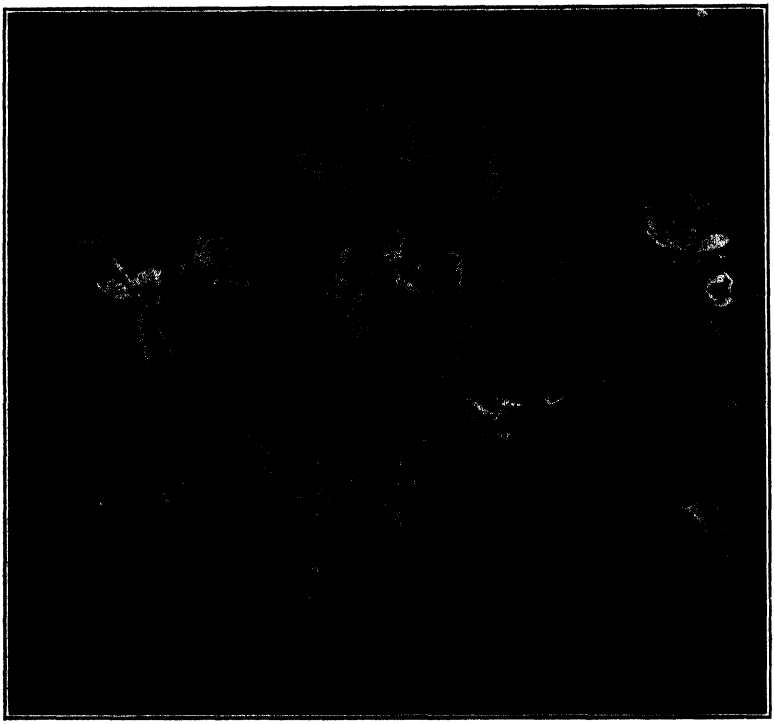

Fig. 54.—The living plant. Hepatica in bloom. (Courtesy of the American Museum of Natural History.)

The movements occur more readily when the temperature is high, and they occur in response to light intensity as well as to tactile stimuli. No hormones have been demonstrated in this connection, but electric phenomena probably do occur, so that it is quite possible that changes in cell permeability following stimulation may account for the amount of water admitted.

Tropisms

A reaction is said to be positive if the growth is toward the stimulus, so that the main axis of the organ is parallel to the direction of stimulus. A reaction is negative if growth is away from the stimulus, but still having the main axis parallel to the direction of stimulus. If the growth is at an angle to the source of stimulus, the reaction is said to be plagiotropic.

Phototropism.—Leaves, stems, and flowers show positive reactions to light. Leaves are plagiotropic, growing so that the upper surface is at right angles to the source of light, while stems grow parallel to the source.

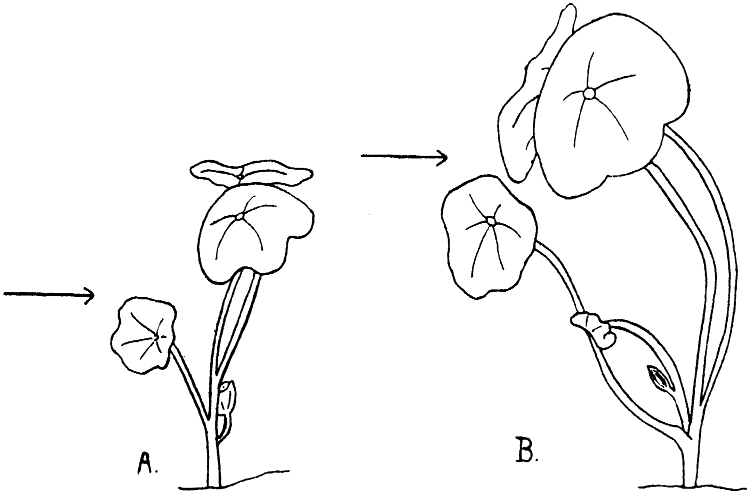

Fig. 55.—Phototropic response in a nasturtium plant. *A*, At the beginning of the experiment; *B*, two days later. The arrows show the direction of light.

In general, leaves are arranged on a stem so as to receive a maximum of illumination. On a plant evenly illuminated, this will be a horizontal position. From the vertical stem, therefore, leaves may grow in any of five directions, but from the branches, the petioles will so twist as to bring the leaves into only two directions.

Intense light, such as is found in a desert or very dry area, tends to draw an excessive amount of water from the plants. Light also has a tendency to kill the chloroplasts in the leaves, so that plants in these areas frequently have leaves which grow at acute angles to the light, thereby causing the rays to strike them less directly.

Geotropism.—The main stem of the plant and the primary root have opposite reactions to gravity. Both grow vertically, the one up, the other down. Growth will be parallel to the stimulus whether the plant be growing on the level ground or on a slope. Young seedlings will demonstrate this in a short time. If planted in a horizontal position, or with the normal position reversed, the young stem and root will each bend at right angles, making complete loops if necessary to regain the normal relation to gravity.

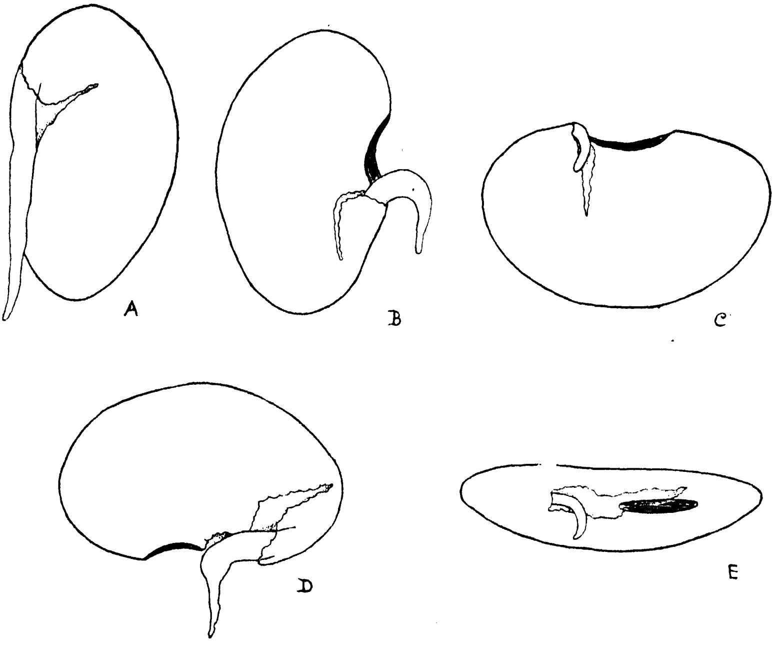

Fig. 56.—Geotropic response of root in bean seeds sprouted in five different positions. *A* is the normal position. In the other positions differential growth causes curvature toward the stimulus. (Enlarged.)

Flowers frequently show definite relations to gravity, and maintain horizontal, upright, or hanging positions, according to their specific sensitivity.

Hydrotropism.—If young roots planted in moist sawdust start growing downward and grow out into the air, they will turn back toward the sawdust and grow along its edge, showing that the root has a positive hydrotropism which is strong enough to overcome the initial geotropism. Usually the side branches are plagiotropic, but these have also a positive hydrotropism, since they will grow long distances to reach water. Even the vertical downward growth is dependent upon water, for a certain amount of moisture is essential to all growth.

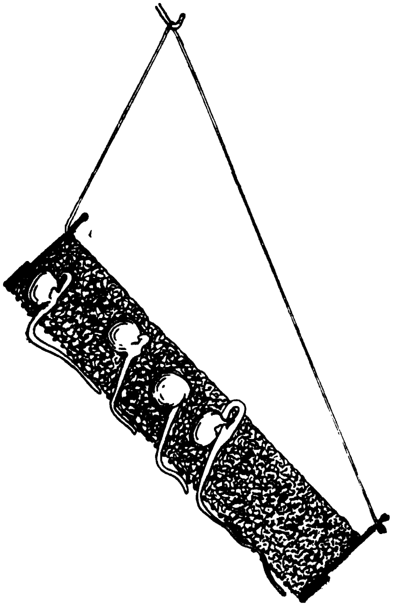

Fig. 57.—Diagram illustrating the hydrotropism of roots. (After Sachs.) (Reprinted by permission from Textbook of General Botany, by Holman and Robbins, published by John Wiley & Sons, Inc.)

Thermotropism.—Roots will demonstrate a differential growth in response to differences of temperature in the medium in which they are growing, which shows that there is an optimum temperature which is favorable to growth. Some plants can stand a warmer climate than others, so that the optimum temperature is specific for the species.

Chemotropism.—Roots show a differential growth toward salt solutions which are unevenly distributed in the soil. This is an advantage, since a variety of salts are needed for food manufacture.

Thigmotropism.—Roots growing underground and reaching a solid object will grow around it. Tendrils of climbing plants grow against and around the object, so that the stimulated side becomes concave. Reactions of the sensitive plant when touched and of the insectivorous plants like the Venus flytrap are examples of thigmotropisms also.

Protection

Such reactions in general bring the plant into the most favorable position for procuring food materials, or for the dissemination of seeds. There are no avoiding reactions, as in the insects, which are in constant danger while procuring their food. The epidermis is the main protective tissue of plants, for by its impenetrable cuticle it holds the water within the plant and thus prevents it from drying up. Drying is the greatest danger faced by plants, although insect enemies are numerous, and against their ravages, plants have such protective structures as hairs, sticky and oily secretions, etc. The stems of the trees have replaced the epidermis with bark, cork, and other resistant structures that are more capable of supporting the plant against winds, droughts, and temperature changes which are detrimental to its growth.

SUMMARY OF THE PHYSICAL FUNCTIONS OF BEHAVIOR

Irritability: Sensitive protoplasm in cells of the meristem. in the petiole, and in the root and stem tips.
Conduction: Diffusion of hormones.
Tropism: Increased or differential growth of cells.
Protection: Hairs, secretions, epidermis, bark, etc.

PHOTOSYNTHESIS

Photosynthesis is a process of manufacture (*synthesis*) by means of light (*photos*). The object of the process is the manufacture of food for the plant. The light comes from the sun in the form of radiant energy. This energy is absorbed by the green pigment of the plant, *chlorophyll.* Some of this energy is transferred during the synthesis into the sugar molecule where it remains as bound energy in a potential form. This makes the sugar molecule the source of all the metabolic energy in plants and animals.

The Raw Materials.—The raw materials used are the inorganic molecules of carbon dioxide (CO_2) and water (H_2O). The carbon dioxide is in the air surrounding the plant. It is always there as the waste product of respiration of plants and animals. Carbon dioxide enters the leaf through the stomata on the under side of the leaf. In the mesophyll cells it comes in contact with the water vapor adhering to the cell walls and is probably dissolved in it since carbon dioxide is always readily soluble in water. The water then carries it to the chlorophyll.

The water is present in the mesophyll cells because of the transpiration process which is continually drawing water from the soil and evaporating it from the leaves. Although much water is always evaporating, the column is continuous so water is always available to the cells.

Chlorophyll.—*Chlorophyll* is one of the plant pigments and is an oxidation product of *carotene.* Carotene is a yellow pigment known also as vitamin A. It is synthesized in the plant cells and then oxidized to form several pigments: (1) *chlorophyll,* which gives the green color to plants; (2) *xanthophyll,* a yellow pigment which gives the color to the leaves of elms, birches, and poplars; and (3) *anthocyanin,* which gives the red color to maple leaves. The yellow and red pigments are found under the chlorophyll in leaves and so do not show until in the fall, when the descent of the sap causes the decomposition of the chlorophyll. Then until the leaves dry and fall off the accessory pigments will give color to them.

Chlorophyll is a complex protein substance very similar in molecular structure to the hemoglobin of the blood. It contains no iron but iron is essential to its manufacture. The carotene from which it is made will not develop in plants in the absence of light, and the formation of the chlorophyll will not occur when soils are lacking in iron.

Source of Energy.—The green color of chlorophyll is due to the selection of rays from the spectrum. If chlorophyll be extracted from a green leaf by boiling in alcohol, the green color will be in the alcohol. If light be allowed to pass through this solution before falling on a prism, the resulting spectrum will show dark bands in the areas absorbed by the chlorophyll. The absorption spectrum lacks some parts of the red area and is almost completely lacking in the blue indigo and violet. The absorption extends farther to include some of the ultraviolet rays. The rays at the red end have heat energy, and those at the ultraviolet end have a kind of chemical energy.

The actual amount absorbed by plant pigments is so minute that it would never suffice in a laboratory to accomplish the synthesis of sugars. In fact, Van Niel, in 1946, experimenting with tracer elements, has suggested that it is not the chlorophyll but enzymes that activate the process of photosynthesis. If so, chlorophyll plays a less active role than is commonly ascribed to it. Enzymes are known to be present in the chloroplasts, however, and since enzymes speed up all metabolic activities, it seems logical to suppose that processes may take place in the chlorophyll in the presence of these enzymes that could never be made to occur in the laboratory.

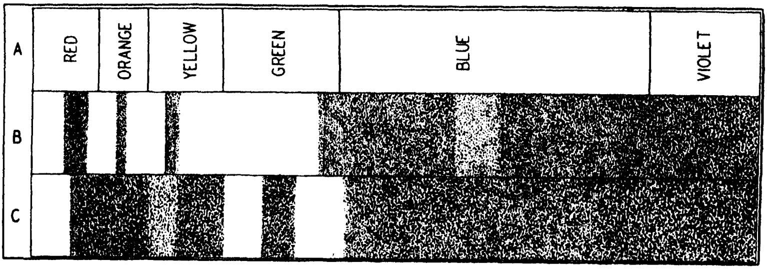

Fig. 58.—Diagram of the absorption spectrum of chlorophyll. *A*, Spectrum of white light; *B*, spectrum of light which has passed through a single living leaf; *C*, spectrum of light which has passed through 63 mm. of an alcohol solution of chlorophyll extracted from a leaf. The dark regions are the absorption bands. (Drawn by Roy K. Marshall.)

The actual amount of light absorbed, therefore, is not as essential as the fact that it is the energy from the sun that is thus made available to the organic world.

The Chemical Process.—The essence of the photosynthetic process is the union of six molecules of carbon dioxide (CO_2) with six molecules of water (H_2O) to form one molecule of a simple sugar ($C_6H_{12}O_6$). The sugar may be in the form of *dextrose* (glucose) or *levulose* (fructose). Both have the same formula. Six molecules of oxygen (O_2) are released by the process and returned to the atmosphere through the stomata.

$$6\ CO_2 \text{ plus } 6\ H_2O \rightleftarrows C_6H_{12}O_6 \text{ plus } 6\ O_2$$

Chemically the process is one of *reduction* and is the reverse of the respiration process of *oxidation*. (See Chapter XII for details.) Since these processes are reversible, and the green plant has a respiratory process also, the cycle is complete in the green plant. The animal, however, has no reduction to match its respiratory process and so is dependent on the green plant not only for the energy of oxidation, but also for the fuel itself, for in the sugars is stored the energy captured in the synthesis.

This outline of the process is correct in representing the beginning and the end of photosynthesis. It does not represent what happens in the plant cells, for metabolic activities are rarely completed in one step and the intermediate products of reduction in the green plant are not yet known with certainty.

Intermediate Products.—It has been supposed that formaldehyde was the first product formed, since minute amounts of formaldehyde have been detected in plant cells, but experiments with radioactive carbon in the carbon dioxide inhaled by the plant have failed to show any of the heavy carbon in the formaldehyde extracted after the test. A substance, the formula of which has not yet been determined, was found to contain the charged carbon.

A more recent suggestion is that chlorophyll itself takes a chemical part in the process. Light rays falling on the chlorophyll are believed to impart their energy to it. It becomes reactive in consequence and joins its molecule with the CO_2 and H_2O, forming a *chlorophyll carbonate*. The enzymes then enter the picture, activating the chlorophyll to give up the union, producing sugar plus free oxygen.

It has always been supposed that the oxygen which returned to the atmosphere was split from the carbon dioxide and contained some of the radiant energy from the sun. In recent experiments with radioactive oxygen, Van Niel has found that when the *heavy oxygen* is in the *water* and plants absorb that water, the *oxygen* given off by the plants during the subsequent photosynthesis consists entirely of heavy oxygen. In the converse experiment, when he activated the oxygen of the *carbon dioxide* molecule and exposed the plants to it, no heavy oxygen appeared in the atmosphere, but the *water* molecules excreted by the plant contained it. The oxygen he used was *oxygen 18,* an isotope of normal oxygen which has an atomic weight of 16. The oxygen was made *radioactive* by exposure to the neutrons of uranium. (See Chapter XI for radioactive elements.) As work with tracer elements is just getting under way in 1946, it may be expected that more and more detail will be forthcoming to clear up the mysteries of metabolism. It may be possible in time to name the intermediate products of photosynthesis with assurance.

It appears from this one experiment that the carbon dioxide and water molecules are completely split apart during photosynthesis and their constituent atoms are rearranged in some still unknown manner to produce the end products of sugar and free oxygen.

Synthesis of Starches.—Wherever sugar is being made, some condensation into starches occurs. It has been suggested that the ultraviolet rays absorbed by the chlorophyll provide the energy for this further synthesis. Starch is the storage form of carbohydrates in plants. Starches are insoluble and cannot be transported through the phloem cells, so wherever starches are found, they have been synthesized in that cell. To be circulated over the plant they must be reconverted into sugars by the reverse process of *hydrolysis.* This is a process of *digestion,* and since the processes are reversible, starches can be digested into sugars and sugars condensed into starches anywhere in the plant at any time, day or night.

Only the initial condensation process is a part of photosynthesis and requires the energy of light.

Synthesis of Fats.—The constructive processes in the plant go further and include the synthesis of fats and proteins. The sugar molecule is used in both processes so the making of the sugars must precede all other activities in the plant. The energy for these additional syntheses comes from the oxidation of the sugars, and the intermediate oxidation products of the sugars are used in the synthesis.

In the case of fats, these intermediate products include *fatty acids* and *glycerin.* The energy from the oxidation causes the combining of the fatty acids and glycerin into fats and oils. This is an *oxidation-reduction* process and by it much of the energy released from the sugar molecules is stored in the fats. As many molecules of sugars must be oxidized to make one fat, more energy is stored in one fat molecule than in any one sugar molecule.

In the synthesis of fats, three molecules of fatty acids combine with one molecule of glycerin. Three molecules of water are released. There are many kinds of fatty acids and any three can be combined in one molecule of fat. This results in a great variety of fats and oils. Their distinctive odors and melting points depend upon the combination of fatty acids in the particular fat.

Fats are stored chiefly in the seeds of plants where they provide food and energy for the growing embryo. These furnish the common oils of commerce; cottonseed oil, linseed oil, peanut oil, olive oil, and the oil of the cocoa bean are familiar examples. The more volatile oils lend fragrance to flowers and leaves and are extracted for perfumes and flavorings.

Synthesis of Proteins.—In the synthesis of proteins the *amino acids* are first formed by combining oxidation products of the sugars with the inorganic salts from the soil. The energy from the *oxidation* is used for the synthesis, so this is also an *oxidation-reduction* process. It is unique in the plant cells. Animal cells can make fat molecules out of sugars, but no animal cell can construct an amino acid.

More than twenty amino acids are synthesized in plant cells, and the growth of animal and plant cells alike is determined by the combinations of amino acids in the complex protein molecules. More than a hundred amino acids may be combined in one protein molecule so these are the largest organic molecules made in any cell.

Only two of the amino acids formed contain sulphur; all contain nitrogen. Nitrates are essential to their synthesis, therefore, and sulphates can be used. Phosphates are combined with the amino acids in the further synthesis into proteins, and no phosphorus is found in the amino acids.

The conditions necessary for amino acid synthesis are complex. They are found in phloem cells and in all meristem tissues. These are regions of cell growth. Protein synthesis can occur in all living cells, green or nongreen, in darkness or in light. Proteins are insoluble in water so must be synthesized in the cells where they are found. To be circulated they must be digested into amino acids.

TRANSPIRATION

Transpiration means the evaporation of water from a plant. This occurs mainly through the stomata of the leaves although some transpiration through the cuticle does occur, so that plants may continue to lose water even though the stomata are closed.

Water rises in a continuous stream from the root hairs which absorb the soil water to the mesophyll of the leaves through the thick-walled xylem cells of the vascular bundle (Fig. 61). Many forces are involved in raising the transpiration stream. It rises against the forces of gravity and in rising presses outward against the cell walls to hold the stem erect.

Osmotic Pressure.—The force exerted on the root hairs is the pressure of the salt solutions in the soil. Absorption is more than simple osmosis, but the force exerted is osmotic pressure. It pushes the column upward through the narrow column of xylem cells, and in some cases the force amounts to forty pounds to a square inch.

Sunlight.—Great as the osmotic force may be, it would not suffice to lift a column of water to the top of a tree. It is the pulling power of the sun's rays that lifts the column upward. The heat in the rays raises the temperature inside the plant and vaporizes the water in the column before it reaches the leaves. Vapor raises more rapidly than water so the warmer the day, the more rapid will be the transpiration.

Cohesion.—The power which causes particles to attract each other is called cohesion. Water vapor has that property when confined in a narrow column, and this cohesion of the water particles to each other and the adherence of the particles to the cell walls exerts a cohesive force which results in the *turgor* which holds the stem erect. The particles against the wall form a thin film along which they flow upward. The rapidity of the movement can be seen when wilting plants regain their turgor after even a small amount of soil water is provided.

Transpiration is not protective. Its chief value to the plant is perhaps the fact that the column brings the nitrates and sulphates from the soil directly to the leaf where they can be used in the synthesis of amino acids needed for the chlorophyll and other plant proteins. A large proportion of the water raised

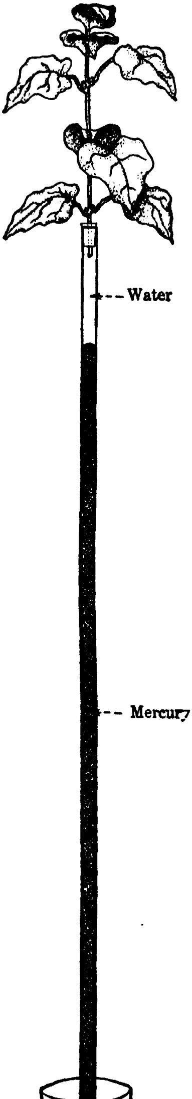

Fig. 59.—Diagram showing method of demonstrating the lifting power of a transpiring leaf surface. The elevation of the mercury column in the glass tube above that in the dish is a measure of this power. (Reprinted by permission from Textbook of General Botany, by Holman and Robbins, published by John Wiley & Sons, Inc.)

is evaporated, and on a hot day, if the temperature inside the leaf is raised, the motion of the particles will be hastened and too rapid transpiration may ensue. Especially if the sunlight is bright, for the intense light may tend to keep the stomata open all day. If too rapid, transpiration may cause the plant to wilt.

Soil water is an important factor, too. If there is a drought and soil water is scarce over a period of time, the pull of transpiration may draw water from the storage organs and from the fruit so that they become shriveled.

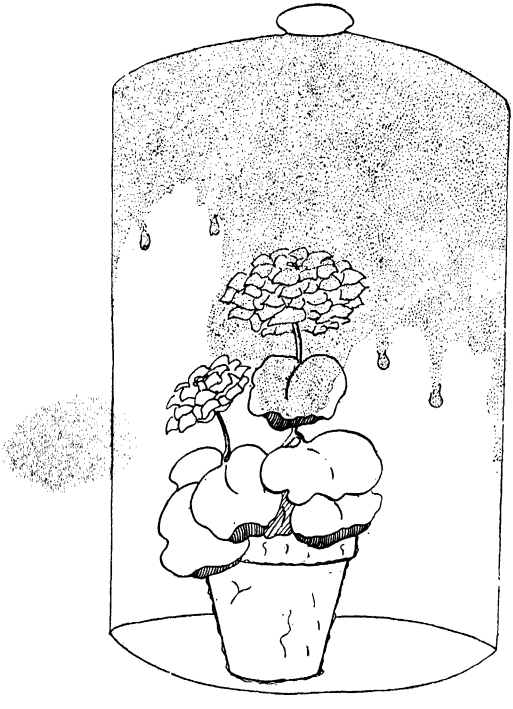

Fig. 60.—Diagram to illustrate transpiration. The pot has been wrapped in tinfoil and the bell jar placed over the plant to exclude water from the air. The drawing was made twenty-four hours after the experiment was set up. The water on the inside of the bell jar had evaporated from the leaves.

Wind currents often hasten transpiration by blowing away the accumulated moisture at the surface of the leaf.

The plant has some protection against excessive transpiration in the cuticle. When the stomata are closed, only small amounts of vapor will escape through the cuticle. Plants vary in the thickness of the cuticle and in the amount of wax or resin in them. Plants that live in the desert, such as the cactus, have very small leaves to reduce the surface for transpiration. The stems are thick and have large storage spaces for water in them. In general, however, the plant depends on the opening and closing of the stomata to regulate transpiration.

The Stomata.—Whether the stomata are open or closed depends upon their *turgidity,* but several factors are concerned in the turgidity.

SHAPE OF THE GUARD CELLS.—Ordinary cells become spherical under pressure. Guard cells become concave. This is because the inner walls facing the pore are thicker and less extensible than the outer walls away from the pore. When water enters the cells, more water will enter through the thin outer walls. The thick walls are then pulled in toward the outer walls to become concave. This leaves an opening. When turgidity is decreased, the thick walls relax and approach each other, thus closing the pore.

ACIDITY.—Even slight changes in the acidity of the medium surrounding the guard cells will affect their behavior. By immersing pieces of epidermis in solutions differing in acidity, the guard cells can be made to open and close at any time, day or night.

A slight decrease in acidity is sufficient to open the pores, while a slight increase will close them. The amount of acidity in any medium is due to its hydrogen ion concentration; an increase in hydrogen ions means an increase in acidity (see Chapter XI).

Changes in hydrogen ion concentration occur whenever a cell is stimulated. Bioelectric currents are set up in the cell which cause the rearrangement of the ions present. Stimulation by light has been found to decrease the acidity by neutralizing the cell interior.

CONCENTRATION OF SUGARS.—Whether *hydrolysis* or *condensation* is the more active process in the cells will determine the water content of the cells and so will affect their turgidity. When hydrolysis is faster than condensation, sugars are being made faster than starches. The increase in sugar concentration will saturate the cell liquids. The surrounding liquids will then be hypotonic and water will enter the cell. This will distend the thinner walls, contract the thick ones, and open the pore. When condensation of starches increases, water is released from the molecule. The starch is deposited in the amyloplasts and the cell liquids become hypotonic to the liquids outside. Water is drawn out of the cell, turgidity is decreased, and the pores are closed. These alternating pressures are often referred to as *concentration gradients.*

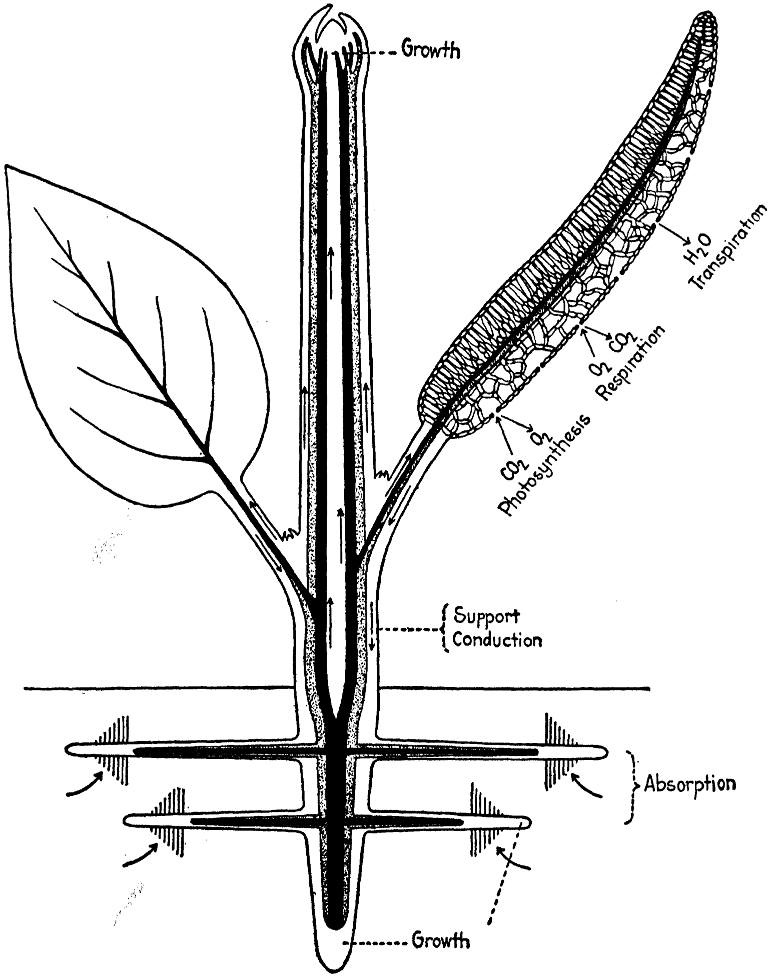

Fig. 61.—Diagram showing the relation of the pathways of conduction to the principal organs and tissues of a seed plant. (Modified after Sachs.) (Reprinted by permission from Botany—Principles and Problems, by Sinnott, published by McGraw-Hill Book Co.)

Light Intensity.—In the morning, when the light rays fall directly on the surface of the leaves, photosynthesis is in progress and sugars are increasing rapidly. While some starch is always being deposited during photosynthesis, the sugar concentrations are in excess. This acts to open the pores just as *hydrolysis* of the starches to sugars does.

In the afternoon, as the light rays come in on more of a slant, the light is less intense on the upper surface and more intense on the undersurface of the leaves. When light falls on the guard cells, synthesis of starches begins, and as the amyloplasts fill, water is drawn out of the cells and the pores are closed.

Depending on what approach one makes to the problem of turgidity, any one of these factors offers a plausible explanation for the behavior of the guard cells. Actually, a chain of events is in progress in which all are involved. In Chapter XI in the section on the plasma membrane it is claimed that stimulation of the membrane of any cell causes changes in hydrogen ion distribution with consequent changes in acidity. Thus the changing intensities of light are sufficient stimuli to cause slight changes in acidity during the day.

Enzymes are very sensitive to acids and alkalies and might be expected to start reverse activities when changes in acidity occur. A very slight decrease in acidity will start up the process of hydrolysis. Since hydrolysis increases the sugar concentration, it follows that the pores will open. In the same way a slight increase in acidity will start up condensation of starches and the pores will close. Thus it appears that each explanation of turgidity changes in the guard cells is one part of a chain of events. Altogether they accomplish the regulatory action of the stomata.

RESPIRATION

Respiration is as necessary for the green plant as for the animal, since the energy for all metabolic activities which follow photosynthesis are dependent on oxidation for the release of energy. Fundamentally the respiration process is one of *oxidation* and it occurs in all living tissues. The external phase of it in the exchange of gases is only important as it provides a measurement of the internal processes.

When plants are in the light, the amount of carbon dioxide in the air around them decreases and the oxygen increases. In the dark, oxygen decreases and carbon dioxide increases,. This does not mean that respiration stops while photosynthesis is in progress, but it does occur at a less rapid rate, and since some of the carbon dioxide released by the oxidation processes is captured in the mesophyll cells and used in photosynthesis without ever being excreted, the respiratory exchange is even less apparent than its rate would indicate.

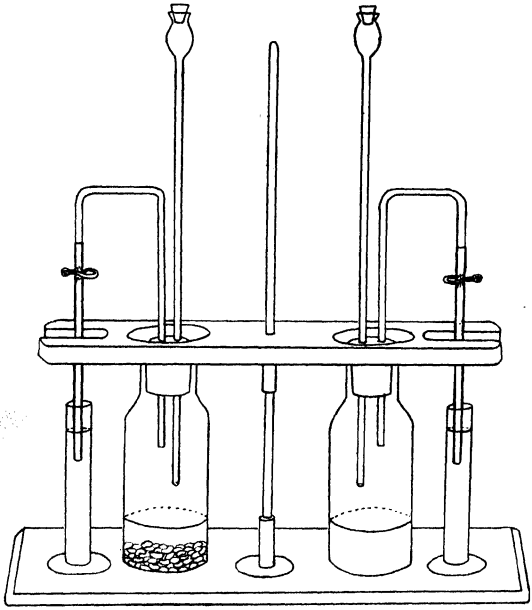

Fig. 62.—Diagram of the respiroscope to illustrate experiment on germinating seeds. For description, see text.

The gas exchange is through the stomata, the lenticels of the stem, and the root hairs. In measurements made of the stomata, the amount of carbon dioxide passing through them is about fifty times greater than the size of the pore would account for. It has also been found that when stomata are close together, less carbon dioxide passes through than when they are farther apart. The area around the stomata, therefore, is more important in gas exchange than the size of the pore.

The intensity of light determines whether photosynthesis or respiration predominates. There are certain periods of the day in the early morning and in the evening when the rate of the two processes is equal. This may happen, also, on dark days. On very dark days respiration may exceed photosynthesis.

Gas exchange through the root hairs is called *aeration*. It is essential to the proper absorption of soil water by root hairs. Even in the presence of adequate soil water, transpiration may cease and plants wilt in the absence of soil oxygen.

Intercellular air spaces ramify throughout the entire plant. They are especially numerous in the mesophyll of the leaf and among the cells of the pith, so that oxygen is available for the oxidation-reduction processes of metabolism at all times.

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} \quad \text{plus} \quad \underset{\text{(oxygen)}}{6\,O_2} \rightleftarrows \underset{\text{(carbon dioxide)}}{6\,CO_2} \quad \text{plus} \quad \underset{\text{(water)}}{6\,H_2O}$$

NUTRITION

The metabolic functions of nutrition are no different in plants than in animals. Once the constructive phases of photosynthesis have been accomplished and starches, fats, and proteins synthesized, plant cells use them as food: *digest* them by *hydrolysis*, *absorb* them through cell walls, *circulate* them through the phloem cells to meristem cells which need them for active growth and to storage organs where they can be kept until needed. When stored, the reverse process of *condensation* recombines the simple molecules into insoluble form. When used by the meristems, the *oxidation-reduction* processes break up molecules by oxidation and recombine them into the type of molecules needed. The energy for the oxidations comes from the *oxygen* brought in from the atmosphere in the *respiration* process. The energy for the reduction processes involved in growth is released by the oxidation process from the sugars or fats oxidized. Proteins can be oxidized but are seldom utilized in this way. The amino acids are used chiefly for growth. (A more complete discussion of the chemistry of metabolism will be found in Chapter XII.)

These processes are less obvious in the plant because there is no division into organs that digest foods and the cells that utilize them. This is unnecessary since no indigestible material enters the plant from which the rest of the body must be protected.

All functions can occur in one cell at the same time. Thus respiration is going on in a leaf even while photosynthesis is in progress. The carbon dioxide resulting from the *oxidations* may be used directly by the mesophyll cells in the synthesis of sugars so that it is not even apparent that respiration goes on. Hydrolysis of starches may be going on in leaf cells at the same time starches are being deposited, and the concentration gradients established by these two processes may account for their movements not only into and out of individual cells, but also up and down the stem.

Translocation

Foods travel up and down the stem through the *phloem* cells of the vascular bundles so have a path quite separate from the transpiration stream. Small amounts of food may move upward in the water of transpiration, but the great bulk of food material is found in the phloem. The *sieve tubes* of the phloem are especially adapted to this movement because of their great length and because of the *sieve plates* which provide direct protoplasmic connections from cell to cell.

Unlike transpiration movements, foods may move either up or down, and while transpiration is most active in the daytime, sap movements are more active at night. They have a seasonal variation, too, movement being principally downward during the winter months and starting upward in the spring.

Recent experiments on phloem flow and on virus movements in plants have seemed to substantiate the theory that foods move by a *mass flow* which is more rapid than either diffusion or protoplasmic streaming. *Pressure* gradients set up by the osmotic pressures of the water in the xylem cells play some part in maintaining this flow, and concentration gradients between the synthesis of foods in the leaves and the growth phenomena in the root hairs determine the direction of flow. According to this theory, the forces exerted by these gradients provide sufficient energy to maintain the mass flow.

Growth

The metabolic processes which result in growth are the *oxidation-reduction reactions.* Energy for the oxidation of sugars and fats comes from the atmospheric oxygen taken in by respiration. The energy released from the foods is used to rearrange the simple molecules of glucose, fatty acids, and amino acids into the complex carbohydrates, fats, and proteins found in the various plant protoplasms. These rearrangements use a form of chemical energy and are constructive processes of *anabolism.* Chemically they are processes of *reduction.* (See Chapter XII.)

Growth is more rapid and more constant in plants than in animals, and more rapid in the regions of primary growth than elsewhere. Growth is also more rapid at night. This is apparently due to a better water supply. During the day water is being carried rapidly to the top of the plant by transpiration, and what is not being used in sugar formation is being evaporated into the atmosphere. At night these processes cease, and the water is available for growth purposes. The food accumulated during the day is also used for growth at night. Thus the long latent period intervening between the receipt of the stimulus by the irritable cells and the response by cell elongation is of advantage in allowing for this accumulation.

There is a continuous growth system throughout the roots, the stem, and the petiole of the leaf. The primary growth tissue is in the meristems; the secondary growth tissue is the cambium. The meristems have almost constant growth; that of the cambium varies with the seasons, being more rapid in the spring and slowing gradually throughout the summer. This can be plainly seen in the annual rings of the perennials. The leaves, having no growth tissue, are secondary structures, and fall when the supply of heat and moisture fails.

In general, animal life is quiescent at night; plants are active day and night. They do have periods of rest, however, when the metabolic rate subsides and the sap runs so slowly as to be almost at a standstill. In temperate regions these periods occur every winter.

Storage

Storage of foods serves a twofold purpose in plants. Starches stored in the stem (celery), in the leaf (cabbage), in the root (carrot), or in the pith of woody plants may be available at any time for *hydrolysis* and so prepared for *oxidation.* This is very similar to the storage in the liver of vertebrates where sugars are *condensed* into animal starch, glycogen, for storage in the liver or muscles and *hydrolyzed* into sugars again for circulation. Three reversible hydrolysis-condensation processes can take place at any time in plants as well as animals.

Food is also stored in permanent storage organs to provide for the next generation. In *annual* plants, like peas and beans, which die at the end of the season, all the food is stored in the seed from which the new plant will grow. In the *biennial* turnips and beets, sufficient food is stored in the roots to provide for a second year of growth. In the woody *perennials,* however, the cells of each year's growth are added to those of the preceding year, giving bulk and support to the stem. The bulk of the dead cells soon exceeds that of the living tissue, and the trees are able to live for many years. In woody stems the cells of the pith and of the pith rays serve as storage spaces for food. Food for the next generation is often stored around the seeds in fruits. Fats are stored chiefly in nuts and in seeds.

Excretion

Because of its rapid growth, one would expect a large amount of nitrogenous waste, but actually the *katabolic* processes are very slow compared with the *anabolic,* and very little waste is formed. Some nitrogenous material is removed, however, through the root tips into the soil, enough in some plants to cause injury by accumulation. Excretory matter is found, also, exuded from glandular hairs in plants that have them. A method of excretion common to most plants, however, is a process known as *guttation.*

On moist, cool nights when the heat of the sun has been removed, transpiration will often stop, even though there is plenty of water vapor present. Then guttation can be observed, for the pressure from within will become greater than normal turgor demands, and sap is squeezed out through the stomata and at the ends of veins where it rounds up into minute spherical drops. It is effective as an excretory process as well as relieving pressure.

In general, however, these are minor occurrences in plants, the dead cells being retained to add, year after year, to the bulk of the plant, and in many cases to function as supporting tissue.

Metabolism

Metabolism is the sum total of all the biochemical activities of the plant, both *anabolic* (constructive) and *katabolic* (destructive). Plant metabolism differs from that of the animal in having the additional synthetic process of *photosynthesis*. This is the reverse of *respiration,* and since the plant has a respiratory process, also, the plant is a complete chemical entity. Animals, however, are dependent on the plants for the completion of the respiratory cycle. Animals cannot exist, therefore, without the oxygen supplied by the green plants.

All constructive processes of metabolism are *endothermal:* they store energy. All destructive processes are *exothermal:* they release energy. A fuller account of the chemistry of metabolism will be found in Chapter XII.

RESPIRATION AND PHOTOSYNTHESIS COMPARED

Respiration	*Photosynthesis*
Oxidation	Reduction
Destructive	Constructive
Energy released	Energy stored
Occurs in all living cells	Occurs in chloroplasts only
Occurs in light and darkness	Occurs in light only
Oxygen admitted	Oxygen released
Carbon dioxide released	Carbon dioxide admitted

SUMMARY OF THE CHEMICAL FUNCTIONS OF FOOD MANUFACTURE AND NUTRITION

Photosynthesis: Chloroplasts in chlorenchyma cells. Sunlight, carbon dioxide, and water.

Transpiration: Root hairs, water conducting tracheal tubes in xylem and mesophyll.

Digestion: Enzymes in all living cells.

Absorption: Diffusion through cell walls.

Circulation: Food conducting cells of the phloëm, sieve tubes, and parenchyma.

Respiration: Continuous aerating system in stem, leaf, and root.

Excretion: Root hairs, guttation, and retention of dead cells.

TABLE OF COMPARISON

	GRASSHOPPER	FLOWERING PLANT
Nutrition	Holozoic	Holophytic
Food	Carbohydrates Proteins Fats	Carbohydrates Proteins Fats
Source of food	Grass	Photosynthesis; chlorophyll bodies in chlorenchyma cells
Irritability	Antennae Eyes Tympanic membrane Palps	Irritable cells in zones of petiole and root tip
Conduction	Ganglia Commissures	Diffusion of hormones
Locomotion	Active: Legs, wings	Passive: Increased or differential growth
Protection	Chitin	Cellulose; cutin
Digestion	Jaws, esophagus, crop, stomach, intestine; gastric caeca and enzymes	Enzymes in all living cells
Absorption	Diffusion through walls of intestine	Diffusion through cell walls
Circulation	Ostiated, tubular heart; lymph in hemocoele	Food conduction cells in phloëm; water conduction cells in xylem
Respiration	Spiracles, tracheal ducts	Intercellular air spaces throughout plant
Metabolism	In all living cells	In all living cells
Storage	Yellow fat bodies	Storage cells of parenchyma
Excretion	Malpighian tubules	Retention of dead cells; root hairs, guttation
Reproduction	Reproductive organs: Egg, sperm	Flower: Ovule, stamen

CHAPTER VIII

THE LIVING CELL

There are many organisms which perform all of the vital activities within the space of one cell. These organisms lack organs and tissues. They include both animal and plant forms and many of them combine the functions of both. For purposes of comparison, an animal cell has been chosen. This is the Paramecium, one of the most familiar of the one-celled types.

PARAMECIUM

Paramecium is an organism easily obtained in all parts of the world. Perhaps the surest source of supply is the well-known hay infusion, for dormant spores of many unicellular animals and plants adhere to dried hay. By placing a small amount of hay in water, the carbohydrates, proteins, and salts of the hay are dissolved in the water. Bacteria are always present in tap water and these multiply in the hay infusion, living on the dissolved food materials. The bacteria provide a source of food for the minute animal forms which gradually emerge from their dormant spores. At first, minute flagellated cells appear, then minute ciliates, and finally the larger ciliates among which will be the Paramecia.

As each form appears, it dominates the culture for a short time. It is necessary, therefore, to transfer the Paramecia to fresh hay infusion during its dominance, for after awhile they will disappear completely. The hay infusion is not a balanced community, for no green plant life is present to use up the carbon dioxide, and the accumulated waste products of the organisms present finally exhaust the infusion.

Structure

The Paramecium is a cigar-shaped organism (the slipper animalcule of the early observers), narrower at one end than the other, with a spiral groove running diagonally into a depression, or *gullet*. The whole cell is surrounded by rows of tiny, threadlike processes, the *cilia*, which grow out from a row of *basal granules* just under the surface of the cell. When moving, which it does incessantly, it revolves about a fixed antero-posterior axis.

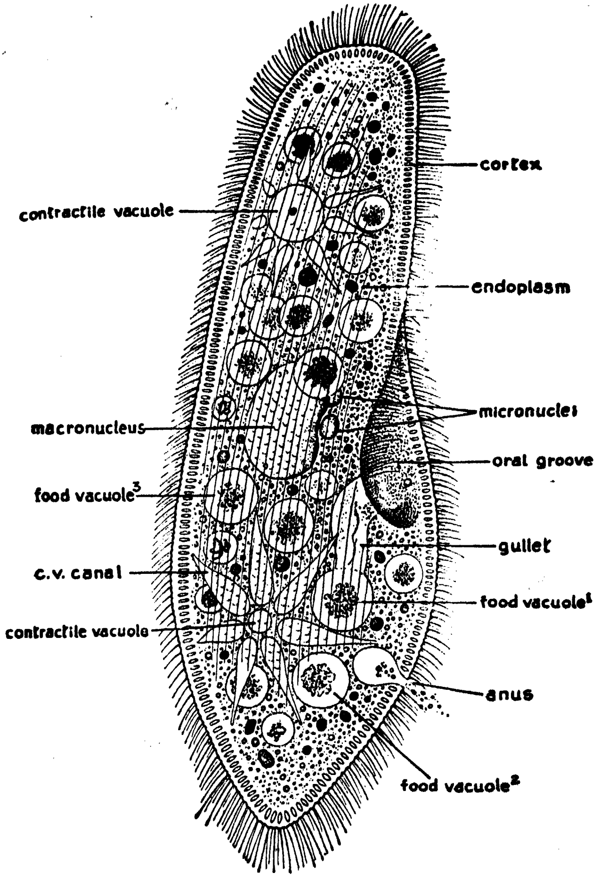

Fig. 63.—*Paramecium aurelia.* (Redrawn after Pfurtscheller wall chart.) (Reprinted by permission from Newman: General Zoology. Published by The Macmillan Co.)

The cell is filled with a liquid, granular protoplasm, the *endoplasm*, about which a more viscous *ectoplasm* forms a stable envelope. A thin *pellicle* secreted by the ectoplasm surrounds the whole cell, and in the ectoplasm will be found the basal granules from which the cilia grow out, and a row of rodlike formations, the *trichocysts.* These give almost a cellular appearance to the ectoplasm but are merely modifications of the protoplasm. They are more easily seen on fixed than on living specimens.

Rees has described a *fibrillar apparatus* with branching fibers connected with the basal granules and trichocysts, and running to the region of the gullet, which he calls the *neuromotor center.*

In the endoplasm there is a current which keeps the granules and vacuoles in constant motion. Two *contractile vacuoles* are fixed in position, one at the anterior and one at the posterior end. They fill and empty their contents rhythmically and alternately, through permanent pores to the outside. A fixed anal spot will be found near the posterior end where solid waste matter can be expelled.

There are two nuclei in the endoplasm just anterior and central to the gullet region. The larger, *macronucleus,* has a somewhat crescentic shape and in the curve of the crescent lies embedded the tiny *micronucleus.*

That this is not a simple cell will be evident from the number of fixed modifications found in it. They cannot be called organs according to the standard definition of an organ, although some authors do depart from the standard to this extent. They can, however, be called *organelles,* a name coined for this especial purpose and thus presenting no cause for confusion. In proportion to their dimensions these organisms are quite as highly differentiated as a grasshopper, but all within the confines of one cell.

Locomotion

It is not difficult to observe motion in the Paramecium; the difficulty lies in keeping it still. It is not so easy, however, to observe the cilia, the vibrations of which cause currents in the water which propel the cell forward. Cilia act in unison with an action somewhat resembling a crawl stroke. As described by Bunker and Jenison, the cilia lift limply, then stiffen and sweep down through the water with real force. This action creates currents in the water and propels the animal forward. The path of the organism is spiral and it

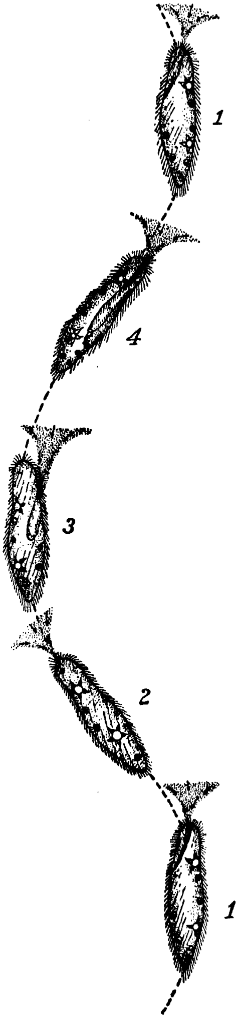

Fig. 64.—Spiral path of Paramecium. The dotted areas show the currents of water drawn from in front. (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

revolves continually on its axis as it moves. Jennings describes this movement as one of *trial and error,* since the Paramecium appears to dart now here, now there; up, down, or to the side, and continually retracts to try a different direction. In spite of this halting mode of advance, progress is rapid. The obvious advantages of this type of progression are that if it meets with sudden danger, it can quickly retract; if it finds a more favorable medium, it can alter its path in that direction.

The typical means of escape is by the *avoiding reaction,* described by Jennings. When an obstacle is met, the action of the cilia is reversed; the Paramecium backs away, gradually turns, and proceeds in a forward direction.

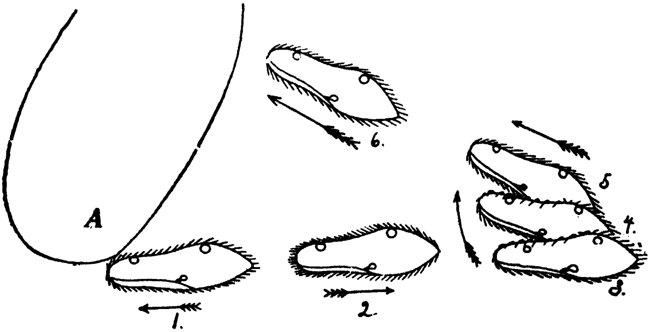

Fig. 65.—The avoiding reaction of Paramecium. (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

Protection

The very path of Paramecium is a protective measure. It has many enemies, some of them much smaller than itself, and it must needs have protective structures as well. The little Didinium, a much smaller ciliate, is one which enjoys a meal of Paramecium, and often succeeds in capturing it in spite of its size. When attacked the Paramecium shoots out the trichocysts in its ectoplasm with such force that the attacking organism may become entangled in threads. As the trichocysts are discharged, the ectoplasm secretes a jellylike substance, so that the threads appear to swell up into a jelly and to force the enemy away mechanically.

It is possible to force the expulsion of the trichocysts by running a drop of iodine, or dilute acetic acid, under the cover glass, but this will inevitably kill the animal.

The ectoplasm further serves as a protective structure by its impermeability, foreign substances in solution being unable to enter the cell unless they are soluble in the lipoids of the cell wall.

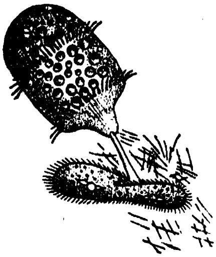

Fig. 66.—Didinium seizing Paramecium. (After Balbiani.) (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

Irritability

The reactions of the Paramecia are tropisms. Therefore, there must be a way of receiving a stimulus, of conducting a stimulus, and of reacting to a stimulus. The reactions have been described. To receive a stimulus, a cell must be *irritable.* Irritability to stimuli is inherent in all protoplasm. Any stimulating agent will cause a local release of energy in an electrically polarized cell membrane. Since this is true in all cells subjected to experimentation, there is no reason to doubt that the membrane around the Paramecium reacts in the same way.

The physiologic state at the time the stimulus is received determines the extent of the irritability, and modifies the response. Such modifications are often erroneously attributed to choice on the part of the organism.

Thus the Paramecium will respond more actively to the favorable chemical stimulus of food, if it has not been fed to satiety, and even then the cilia will continue to sweep food into the gullet as long as any remains in its presence.

The presence of one agent may alter the response to a second which might be definite and vigorous in the absence of the first. A Paramecium in contact with a solid will react less quickly to unfavorable chemicals than when free. Thus a stronger irritability may cancel a weaker one, even to the destruction of the organism.

Reactions are adaptive as in the grasshopper. The positive reactions are toward favorable conditions, the negative ones away from danger; thus the organism continually adjusts itself to a changing environment. Not all reactions are definitely positive or negative. Toward heat, Paramecium reacts differently according to temperature. At 30° C., it reacts negatively to any rise in the temperature, but shows no reaction to lower temperature. At 20° C., it reacts negatively to lower temperatures, but gives no reaction to higher ones. Therefore, the range from 20° to 30° C. is the optimum temperature for Paramecium.

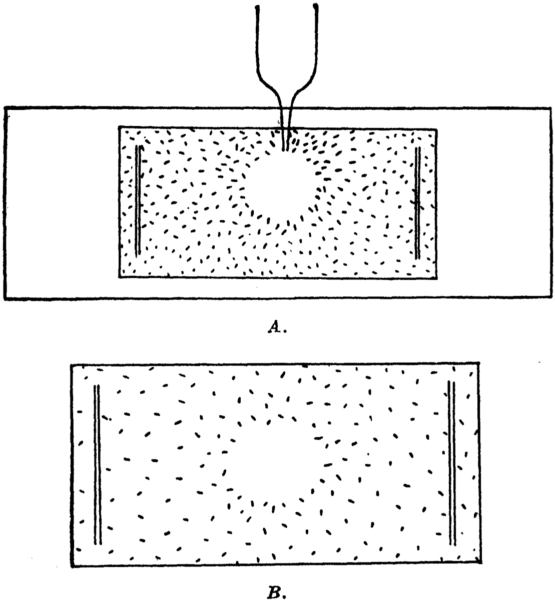

Fig. 67.—Reaction of Paramecia to a drop of ½ per cent NaCl. *A*, Method of introducing drop; *B*, four minutes later. (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

It shows no definite reaction to light visible to man, although to ultraviolet rays it gives a negative response.

A few responses of Paramecia can be observed without the aid of a lens if the specimens are abundant. The water should be free from obstacles. If a grain of salt be placed in the center of the drop containing Paramecia, a general exodus toward the rim will be noted. To observe reaction to heat a flat Petri dish is preferable, as a microburner can be brought against the center of the under side of the dish.

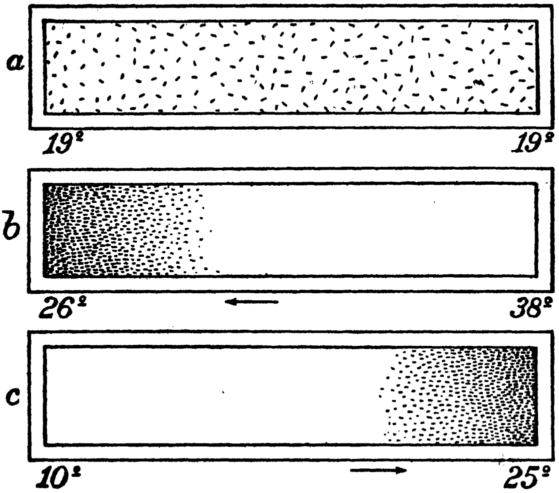

Fig. 68.—Reactions of Paramecia to heat and cold. At *a* the Paramecia are placed in a trough, both ends of which have a temperature of 19° C. They are equally scattered. At *b* the temperature of one end is raised to 38° C., while the other is only 26° C. The Paramecia collect at the end having the lower temperature. At *c* one end has a temperature of 25° C., while the other is lowered to 10° C. The Paramecia collect at the end having the higher temperature. (After Mendelssohn.) (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

Conductility

The energy released by the stimulus must be transferred to the motor mechanism where the response is to take place. The fibrils of the neuromotor apparatus seem to provide a pathway for the stimulus. What the stimulus is is not clear. No experimentation has been done on the Protozoa, but neurohormones are being identified in more and more species, including the invertebrates, and the similarity of their action to that of the plant hormones seems to offer good evidence that chemical conduction is more primitive than nerve conduction. In that case it is at least an open question whether the stimulus is carried over the neuromotor apparatus by hormones or by some incipient nerve activity.

Summary of the Physical Functions of Behavior

Sensation: Irritability of the protoplasm.
Conduction: Neuromotor apparatus.
Locomotion: Cilia.
Protection: Trichocysts and pellicle.

Digestion

As the Paramecium moves through the water, the cilia at the mouth of the spiral groove create a current which directs small amounts of water down to the gullet. Whether there is food present or not, these small quantities of water collect in a pocket at the base of the gullet and are there surrounded by a liquid. A spherical vacuole is formed which is at once caught up in the currents of the protoplasm and swept into the general stream. The process can easily be observed by placing the Paramecia in carmine or India ink suspensions, the particles being ingested regardless of their lack of nutriment. They are eventually removed at the anal spot. The dependence of Paramecium upon a favorable environment is thus apparent, for it has no way of distinguishing between material which is edible and that which is not.

If bacteria are plentiful in the culture, it may be possible to observe the swelling which takes place soon after the *food vacuole* is formed. This is caused by the free hydrochloric acid which is secreted in minute amounts by the endoplasm surrounding the vacuole. This prepares the food for digestion by the enzymes which are likewise secreted into the vacuole.

If cream is used for the observations, the whole process of digestion can be seen. The Paramecium should first be stained with a solution of neutral red which is a vital stain and one that will be readily absorbed into the cell. It has the added advantage of being an acid indicator, turning pink in an acid and orange in an alkaline medium. Alizarin may be used equally well, the reactions being much the same except that the acid reaction is a reddish violet and the alkaline a clearer yellow.

With neutral red the granules immediately surrounding the food vacuoles become bright red while the rest of the protoplasm is colorless. It is believed, therefore, that these granules are the secreting structures of the cells and that they empty their contents into the food vacuoles. The granules have even been observed to enter the vacuoles. The contents of the vacuole will be red also, and the vacuoles will move with the currents of the endoplasm round and round the cell, the motion being forward on one side and backward on the other so that the complete *circulation* of the contents is assured.

As the vacuoles proceed around the cell again and again, they can be seen to change in color, gradually assuming the orange hue. This is a clear indication that the medium of the vacuole is changing from acid to alkaline which would be the condition if the enzymes were changed from the peptic to the tryptic variety, as in the higher forms. There is no indication of any digestion of carbohydrates in Paramecium, and starch is ejected unchanged. Therefore, while it has never been definitely proved that the enzymes present are pepsin and trypsin, the inference is clear.

While the digestion is going on, the vacuole is growing smaller and smaller, and will finally disappear. This is caused by the *absorption* of the food as it is digested into the endoplasm where it will be immediately available for metabolism. Thus digestion, absorption, and circulation are all accomplished simultaneously by the food vacuole, which becomes an important, though temporary, organelle.

Respiration

Respiration in Paramecium is a simple process of diffusion, the gaseous exchange taking place through the ectoplasm. It can be demonstrated that oxygen is necessary for the release of energy, since the removal of oxygen from the water causes the cilia to stop beating and the Paramecia come to a standstill as though anesthetized. By alternately adding oxygen and carbon dioxide the movement can be controlled. Some of the carbon dioxide is probably excreted with the excess water through the contractile vacuoles.

Metabolism

Metabolism in Paramecium is both constructive and destructive. There is a limit of growth, and when the limit is reached division takes place, making two Paramecia. The rate of metabolism at any time may be measured by the division rate. During periods of optimum growth the cells divide as many as three times a day, but during periods of depression the rate is much slower and frequently division is suspended for a time.

In addition to the secreting granules which accumulate about the food vacuoles, there are a great many granules in the endoplasm which apparently serve as storage structures, holding the food materials in abeyance until needed. That this is their function is shown by the fact that they are almost completely absent in starved individuals.

Excretion

The excretion of nitrogenous waste is generally believed to be accomplished by means of the contractile vacuole. Various functions have been assigned to the contractile vacuole, among them a partial respiratory process and the maintenance of equilibrium in the cell. In fresh water forms, such as Paramecium, it is probable that the excretory function is paramount.

The process of gathering in the wastes and excess water can be observed. Narrow slits of clear solution appear around the permanent pore, giving a starlike appearance. As they gradually fill, they enlarge until the contents flow together to form one globular vacuole. A sudden contraction empties the contents into the surrounding water and the process begins anew. The action of the two vacuoles is alternate and rhythmic.

The continuous process of excretion is essential in the Paramecium, since otherwise, the cell would swell up and burst from the effect of the continual ingestion of water which is swept in minute quantities down the gullet, whether food is present or not. The removal of this excess is quite as important a function of the contractile vacuoles as the removal of the nitrogenous wastes and salts. There is some evidence that carbon dioxide may be excreted in this way, but by far the greater part of it is excreted by diffusion.

SUMMARY OF CHEMICAL FUNCTIONS OF NUTRITION

Digestion:	Temporary food vacuoles, enzymes.
Absorption:	Diffusion from food vacuole.
Circulation:	Currents in endoplasm.
Respiration:	Diffusion through ectoplasm.
Excretion:	Two contractile vacuoles, fixed.

LIFE CYCLE

Heretofore we have spoken of the Paramecium and the other Protozoa as organisms complete in one cell; this is only partially true, for, while the cell fulfills all the requirements of self-preservation, it plays only a minor rôle so far as race-preservation is concerned.

The life cycle of Paramecium is not completed by the mere act of fission; a second type of reproduction, the sexual phase, must intervene. There is thus an *alternation of generations* in which the asexual phase alternates with the sexual phase to make a complete life cycle. Any individual formed in the process is a part of the cycle, and only the complete cycle can be looked upon as the organism.

Asexual Phase

By asexual reproduction is meant the multiplication of individuals without the previous union of two cells, or gametes. In Paramecium this is accomplished by simple fission. There appears to be a constriction at the center of the cell, a new gullet forms in the posterior half, and the two cells separate. The macronucleus constricts and divides in the same way, but the micronucleus behaves in a strange and complicated manner, which can only be seen in fixed specimens. In the micronucleus are 128 chromosomes, and in the division of the nucleus each of these chromosomes is accurately divided into two parts, so that each cell receives one-half of each chromosome, or 128 chromosomes. The mechanism which provides for the accurate division of this material is called *mitosis*.

The nucleus of Paramecium is in two parts and has two distinct functions, the macronucleus containing the vegetative material and the micronucleus the kinetic material needed for the initiation of cell division. In the macronucleus, therefore,

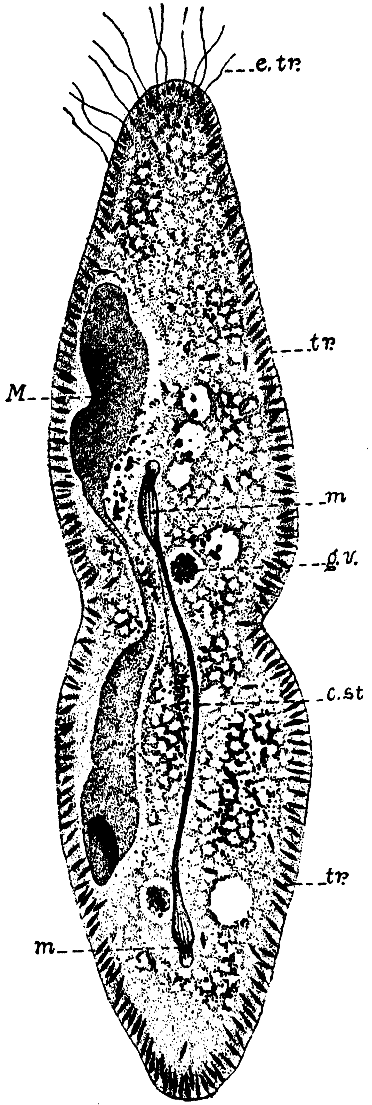

Fig. 69.—*Paramecium caudatum.* Section of a dividing specimen. *c. st.*, Connecting strand of dividing micronucleus; *e. tr.*, extruded trichocysts; *g. v.*, gastric vacuole; M, dividing macronucleus; *m, m*, divided micronuclei; *tr.*, trichocysts. (Reprinted by permission from Calkins: Biology of the Protozoa. Published by Lea & Febiger.)

lies the potentiality of the activities of the individual; in the micronucleus lies the potentiality of the race.

The macronuclear material, therefore, will wear out in time unless it is replenished from the energy of the micronucleus. Each time that the Paramecium divides, there are formed two cells. Neither is parent and neither is child, for the parent protoplasm is absorbed into the offspring. There has been no change except in number and as the process goes on, the numbers increase, all parts of the same protoplasm, with the same nuclear material. But the potentiality is not the same. This shows itself in the lowering of the division rate, and finally the cells come to rest in a dormant condition from which they can be aroused by the process of conjugation.

The individual paramecium, therefore, of which there may be hundreds by the time the depression period is reached, is not a complete organism at all; it is only one cell of an organism in which, at any given time, the condition of the protoplasm represents the age and potentiality of the organism as a whole.

Sexual Phase

CONJUGATION

In any culture of Paramecia there will occur this period of depression during which the individuals will cease their activities and will be found in a quiescent condition. At such a time, normally, they will be found in pairs, the protoplasm of the two united in the gullet region so as to form a bridge between them. This is called *conjugation,* and is a primitive expression of sexual union in which the two gametes are equal in size and function.

The details of the process are of importance in arriving at an understanding of fertilization, and the probable reasons for sex differentiation. It will be seen from the diagram (Fig. 71) that it is essentially a process of the micronucleus; the macronuclear material eventually breaking up and being resorbed into the protoplasm.

The process is the same in each cell, two equal divisions being followed by an unequal one. Only one of the four participates in this unequal division, the other three degenerating. There are now in each cell one large and one small nucleus, and the smaller one of one cell migrates across the bridge of protoplasm into the other cell where it unites with the larger nucleus of that individual. This is the real fertilization process and is one of the simplest illustrations of sex differentiation. The union of the two cells is comparable to the copulation process in animals.

The fertilized nucleus now divides three times in quick succession, the while the two individuals break apart and the old macronuclear material is actively resorbed. Of the eight nuclei now present in each cell, four will make micronuclei and four macronuclei in four new individuals. The cells lie dormant at this stage for from thirty to forty-eight hours during which time the differentiation between the nuclei takes place, not by unequal division but by growth of the four which are to become the macronuclei.

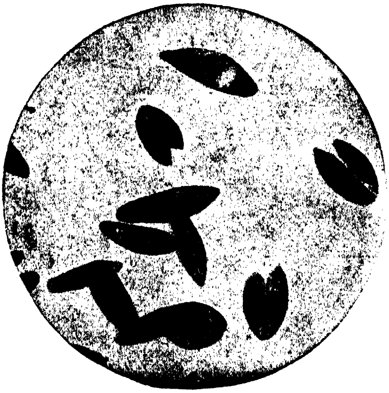

Fig. 70.—Paramecium. Photomicrograph of specimens in conjugation. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

When this increase in bulk is accomplished, two divisions of the entire cell follow, the macronuclei and micronuclei being distributed among the four without further division, thus restoring the normal condition of the asexual individuals. This completes the conjugation process. From the two participating cells there are now eight ex-conjugants, each of which represents the beginning of a new organization; a newborn organism with renewed vitality. Only between these eight

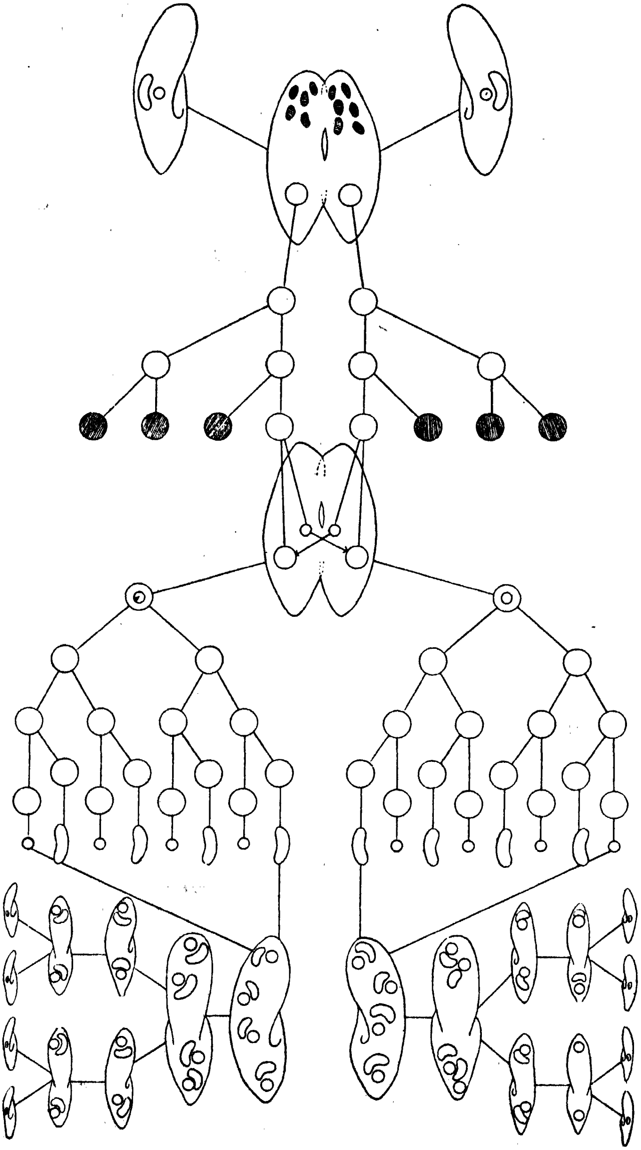

Fig. 71.—Diagram showing the behavior of the micronucleus during conjugation in Paramecium. Circles denote micronuclei; crescents, macronuclei. Shading denotes the resorption of material. The divisions of the micronuclei are represented outside the cell.

cells is there any possibility of variation in the Paramecium, all the cells which result from the division of any one of them being exactly the same, except as conditions of nourishment may cause them to vary in size.

The complete history of the organism with this alternation of the asexual divisions with the conjugation period is called the life cycle of the organism. If the cycle is completed, there will be no natural death in the race, all the material of the parent being absorbed into the offspring.

VITALITY

Whether natural death is the normal sequence to life, or whether it is the penalty paid by the higher organisms for the advantages of specialization is a question which was raised by Weismann more than thirty years ago, and has been examined by scientists almost continuously since that time. It is now a well-known fact that cells can be removed from the higher organisms and, under constant conditions of temperature and moisture, can be kept alive for years, even propagating outside the body, though never giving rise to cells any different from themselves. Cancer cells have been transplanted from mouse to mouse for more than a hundred generations without any loss of vigor, and connective tissue cells have been found still dividing at the end of ten years. Without any doubt, therefore, the tissues of the higher organisms do pay the penalty of subordination to the whole. In the Protozoa there is no such subordination. In the Protozoa, therefore, must lie the answer to the question.

Maupas, Calkins, and Woodruff have been the chief investigators of this question, and the evidence to date appears to be conclusive in demonstrating that a waning of vitality followed by ultimate death is the fate of the one-celled organism, unless it is provided with some means of reorganizing its kinetic material. Conjugation normally accomplishes this purpose, and Woodruff has found that in some species of Paramecium, notably *Paramecium aurelia,* a process of endomixis, which occurs inside the cell without conjugation with another cell, furnishes the same renewal of vitality.

In the organisms which do not have the ability to reorganize by endomixis, a definite cytoplasmic change accompanies the waning of vitality, and conditions simulating old age appear. When this happens in *Paramecium caudatum,* the cytoplasm is filled with vacuoles, and no amount of stimulation will induce further division.

During the past ten years a series of experiments on Uroleptus, a ciliate Protozoan, has strengthened the position of those who believe that natural decline in vitality is the heritance of all protoplasm. In Uroleptus there is no sign of endomixis, and every precaution to provide normal feeding conditions has been taken, but the organisms continue to show waning vitality with death when conjugation is prevented by the isolation culture method. By this method the ex-conjugants are isolated in separate culture dishes, and each day one is removed from each dish to fresh culture medium. In this way the division rate can be determined and conjugation prevented.

Fig. 72.—*Paramecium caudatum* in a period of depression, and recovery after treatment with salts. (Reprinted by permission from Calkins: Biology of the Protozoa. Published by Lea & Febiger.)

Calkins found the rates for Uroleptus to vary only slightly in twenty-three series. During the first sixty days the rate was 15.4 divisions per ten days. From this rate it decreased at ten-day intervals until death occurred. Many other Protozoa have been given similar treatment, and the general results show that much the same process is going on in all.

The criticism that abnormal feeding conditions account for all waning vitality is still being made constantly, but this has been controlled most carefully in the later experiments, and while the question can by no means be considered settled, it is certain that the life cycle shows characteristic changes in vitality during its progress, whether death eventually intervenes or not.

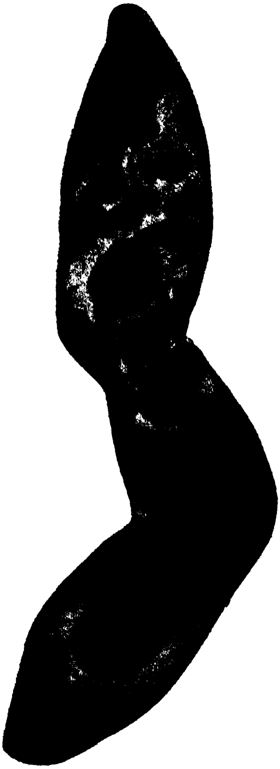

Fig. 73.—*Paramecium caudatum* monster, a type common at periods of old age. (Reprinted by permission from Calkins: Biology of the Protozoa. Published by Lea & Febiger.)

These changes in vitality are due to the using up of stored energy, which in Paramecium is apparently stored in the macronucleus. The restoring or reorganizing is accomplished by the activities of the micronucleus.

SIGNIFICANCE OF CONJUGATION

Conjugation being the normal sequence of a period of lowered vitality, and being one of the simplest forms of fertilization, throws some light on the relation of fertilization to the reproductive process. It was formerly supposed that fertilization was synonymous with reproduction, but it has been proved to be an accessory process developed to make certain the reorganization of the chromatin material. In highly specialized forms, it is the only means of initiating reproduction, but if reorganization can take place by endomixis, the union of two cells is, obviously, not essential.

What fertilization does accomplish is *variation.* Without the union of two cells and the consequent rearrangement of the chromatin material, the organization of all cells would remain the same. Fertilization assures a distribution of hereditary material which is the only means of change within the species. To be sure, environmental conditions may cause some variation in size and physiologic state among individuals of the same organism. This is due to differences in food supply, temperature, or other conditions to which the cells are sensitive; but when the averages are taken and the entire life histories compared, there are decided differences in the eight exconjugants which are easily distinguished from the environmental distinctions.

SIGNIFICANCE OF BEHAVIOR

In the protoplasmic response of a one-celled organism to stimuli, we have the unit of all behavior, just as in irritability we have the unit of sensation, and in contractility the unit of muscular contraction. To understand the units of function, it is only necessary to follow the physicist in his researches into the atom. The physicist sees energy as well as matter existing in space as material units, called electrons which have their origin in the sun.

The building up of electrons into atoms, of the atoms into molecules, and of the molecules into protoplasm accounts for the lowly organization of the one-celled organism. Thus the complex animal activities may be looked upon as the gradual grouping together of functional units into more and more highly differentiated form. As the contracting muscle grows from the unit of contractility, and the reflex arc from the unit of conductility, so, also, may units of consciousness build gradually into the awakening of that awareness from which memory and association may grow.

Just where true awareness begins it is impossible to determine, but in its development there have been left over instincts and reflex responses which correspond to the simple conditions of former times. Thus it is important to study the one-celled organism, and by understanding the units of its activity to comprehend better the higher forms.

CHAPTER IX

UNICELLULAR ORGANIZATION

Organization is one of the most remarkable things about living organisms. It is that property which makes a Paramecium a Paramecium, and a grasshopper a grasshopper. It is so deeply laid in the molecules of the protoplasm that not even the removal of the nucleus makes any change in the organization of a cell. So impervious is it to alteration that nothing short of germinal mutation can change it. In organization, therefore, lies the secret of species identity.

That this organization is located in the cytoplasm, and not confined to the nucleus, is shown by the behavior of unicellular organisms when cut into parts. A small piece of a Stentor will regenerate a new Stentor; the fragments of a Paramecium will make Paramecia, and the pieces of Uronychia will make another Uronychia. No matter how small the fragment, therefore, the species identity is retained.

In spite of the resistance to change in the fundamental organization, however, adaptations do take place. It is through the adaptability of protoplasm to changed conditions that progressive development has been made possible; in the plant and animal kingdoms as they exist today the organisms appear to be so perfectly adapted to their environment that it is difficult to consider them apart from it. Thus, the multifarious specializations in the animal kingdom bear a definite relation to the active search for food, while the very passivity of the plant is an expression of its food-making power.

Among the unicellular types of life must be found those organisms through whose activities progressive development became possible. The ancestral lines of both plants and animals lead back through successively simpler and simpler forms until they merge in forms which are both plant and animal, and the distinction between the two kingdoms ceases to be.

The relationships within the unicellular groups are difficult to establish, and the classifications of plants do not recognize the unicellular organization as distinct from other simple forms. It is true that in the plants they merge almost imperceptibly into the filamentous type, but in some respects unicellular types have reached a higher degree of specialization than some of the lower tissue organisms.

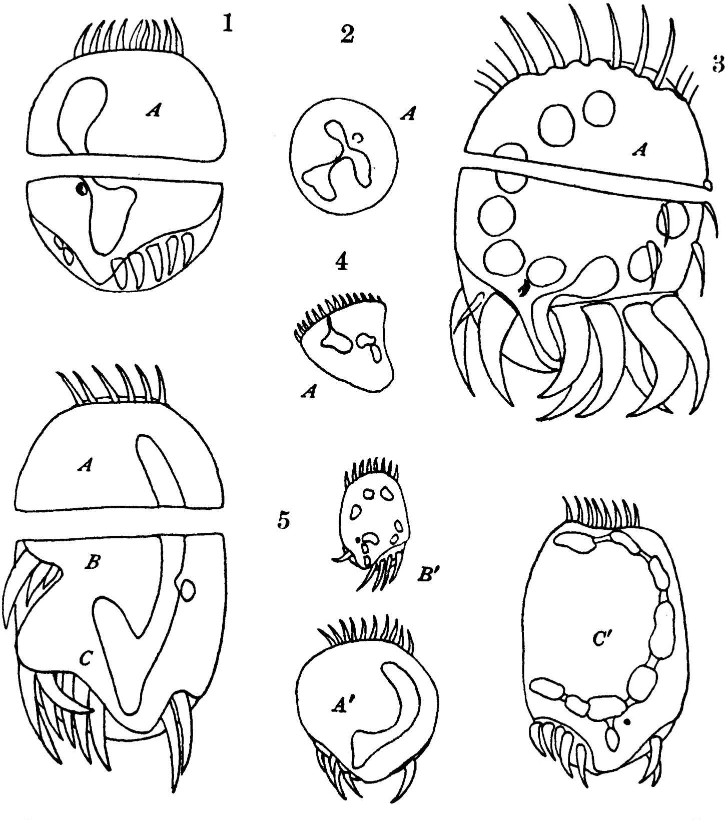

Fig. 74.—Merotomy and regeneration in Uronychia. *1,* Cells immediately after division, cut as indicated; *2,* fragment *A* of *1,* three days after operation, no regeneration; *3,* cell cut five hours after division; *4,* fragment *A* of *3,* three days after operation, no regeneration; *5,* cell cut at beginning of division as indicated, into fragments *A, B, C; A′, B′, C′;* fragments *A, B,* and *C,* twenty-four hours after the operation; fragment *A* regenerated into a normal but emicronucleate individual, *A′; B* and *C,* divided in the original division plane forming a normal individual, *C′,* and a minute but normal individual, *B′.* (Reprinted by permission from Calkins: Biology of the Protozoa. Published by Lea & Febiger.)

Three groups of unicellular organisms may be recognized: the bacteria, the one-celled green algae, and the one-celled Protozoa. Three main tendencies have been expressed in their development, and since these have been paralleled in the animal and plant forms, and in some respects have interlaced, the three groups are considered here together.

The tendencies in development are:

1. The establishment of nutritional types.
2. The division of labor between cells.
3. The aggregation of cells into colonies.

Of these the establishment of nutritional types is of first importance, since the basic distinction between animals and plants is one of nutrition.

NUTRITIONAL TYPES

1. *Autotrophic*—synthesis of inorganic substances into organic compounds. Entirely independent.

a. *Holophytic*—photosynthesis; chlorophyll absorbs light for energy. Green plants.

b. *Chemotrophic*—chemosynthesis; oxidizing inorganic compounds for energy without chlorophyll or sunlight. Sulphur, iron, and nitrogen bacteria.

2. *Heterotrophic*—require organic food compounds, therefore dependent on autotrophic organisms.

a. *Holozoic*—ingestion of organic food compounds, involving capture, digestion, and egestion of residue. Most animals.

b. *Saprozoic*—ingestion of dissolved food compounds by absorption, eliminating capture, digestion, and egestion of residue. Some simple animals, frequently parasitic.

c. *Saprophytic*—absorption of organic compounds derived from dead tissues or their products. Digestion, if present, is external. Some bacteria, molds, mushrooms.

d. *Parasitic*—obtaining food from living organs with external digestion. Some bacteria. (Parasitism may be found in many groups of animals and plants. As a nutritional type the term is applied to external digestion of foods.)

3. *Mixotrophic*—a combination of autotrophic and heterotrophic nutrition in one organism. Many flagellates, insectivorous plants, etc.

Nutritional types are mutually dependent, and since the ultimate source of energy in the organic world is in the materials of the inorganic world, it is the autotrophic types which keep the stream of life in motion. The photosynthetic types must depend for energy on the oxygen of the atmosphere. The energy of light is sufficient only to carry the synthesis of sugars to completion. All other metabolic activities depend on oxidation just as in the holozoic types. Chemotrophic types are the only forms of life completely independent of other organic forms. They can cause the oxidation of such inorganic compounds as hydrogen sulphide gas. When oxidized by the sulphur bacteria this gas yields sulphuric acid, and enough energy is released by the process to activate the metabolic activities of the bacteria. Some heat is liberated also. The iron bacteria oxidize iron in the same way, and nitrogen bacteria oxidize the nitrites and nitrates in the soil.

Chemotrophic bacteria, therefore, are the only forms of life which are completely independent of the the organic world for their own existence. It is probable, therefore, that this type of nutrition antedates all others and that some such organisms as these were the first effective compounds to form self-preserving and race-preserving systems. In the viruses which combine some of the attributes of life with some inorganic properties scientists have found the long-sought link with the inorganic world.

Bacteria

The bacteria are one-celled plants, lacking in chlorophyll, and without organized nuclei. They have been included with the Fungi as colorless thallophytes, but this is so artificial a distinction as to give no idea of their relationships. They are described at this point because the chemotrophic forms are probably the basic living organisms, and because they form a pivot through which the stream of life flows steadily from animal to plant (see page 194).

Cell Structure.—The cell of the bacterium is unique in that the nuclear material is not confined within a limiting membrane, so that no true nuclei are formed. The chromatin may be scattered throughout the cytoplasm in granular form, or may be aggregated into clumps, but in either case the nuclear membrane is absent. This is doubtless a primitive characteristic.

The *cell wall* is double. The inner wall is very thin and elastic, and corresponds to the living membrane about the ectoplasm of the Protozoa. The outer wall absorbs water, a function known as *deliquescence.* Sometimes a *capsule* is formed like a halo about the cell. Sometimes *chitin* forms in the wall, but cellulose, that substance so characteristic of the plant cell, is very rarely found.

Motility.—Bacteria may be motile or nonmotile, but in most cases they have the appearance of motion due to the vibrations in the liquid. This transmitted motion is caused by the molecules and is called Brownian movement (see page 67). It is not the result of any activity on the part of the protoplasm of the cell.

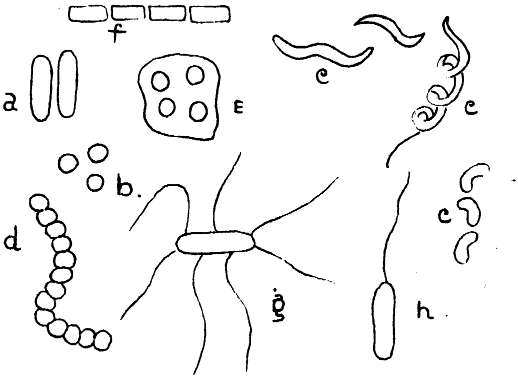

Fig. 75.—Types of bacteria. *a,* Bacillus; *b,* coccus; *c,* spirilla; *d,* streptococcus; *e,* tetrad; *f,* streptobacillus; *g* and *h,* flagellated forms.

The motile forms are provided with whiplike flagella, long protoplasmic threads which penetrate from the endoplasm and extend into the surrounding liquid. There may be a single flagellum, a tuft of flagella, or a general distribution of flagella over the cell. The spirochetes, which are among the larger of the bacterial types, have a flexible form in addition to the flagellum, and move by sinuous movements of the entire cell. These have been compared to the movements of the undulating membrane on the flagellum of the trypanosomes, which are colorless flagellated Protozoa. There is no ground, however, for homologizing the morphologic features of the spirochetes with those of the trypanosomes, so the relationship is doubtful.

Reproduction.—Reproduction is chiefly by simple fission, frequently occurring as often as three times in an hour. This terrific rate cannot continue for any length of time, however, as the metabolic activities incurred invariably exhaust the organisms. This may be due to the failure of the food supply or to the accumulation of waste products.

Fig. 76.—*Bacillus typhosus.* Photomicrograph from a slide stained to show the flagella. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

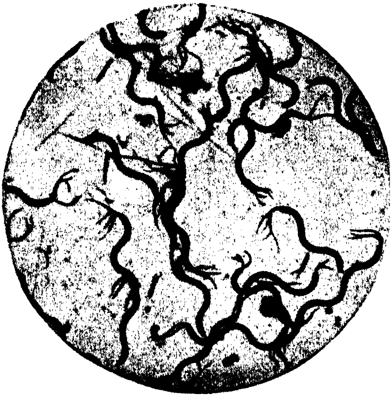

Fig. 77.—Spirillum. Photomicrograph of a giant species. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

Should the rate continue, it would take but a few days to accumulate a mass which would drive all other living things from the earth. In two days the mass accumulated by the most rapid multiplication of the cholera organism would weigh over a trillion tons, and the number of individuals formed would be

2 to the 96th power, a number with 28 ciphers. (Holman and Robbins.)

Nothing resembling a life cycle can be demonstrated in the bacteria, although attempts have been made to homologize certain granular stages with sexual reproduction. There is, however, a period of rest in the life history, which accomplishes recovery from the fatigue engendered by extreme activity. This is known as spore formation, and is characteristic of bacteria, but is not a universal function.

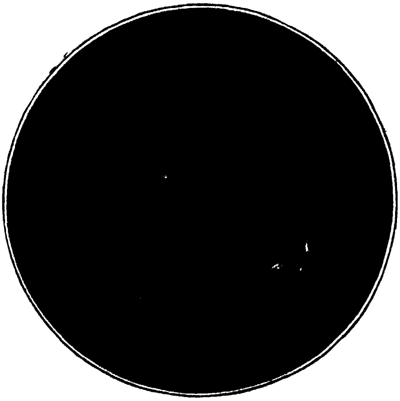

Fig. 78.—*Clostridium tetani.* Photomicrograph showing spores. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

Spore Formation.—The spore is formed inside the cell, and is preceded by a concentration of the nuclear material. The wall becomes very resistant, and there is complete cessation of activity. Spores can be heated to 70° and some even to 100° C without harm, and can be dried over a period of decades (even eons, if recent discoveries are to be credited) without loss of potentiality.

This is not a reproductive function, but a rest period which assures the preservation of the organism over long periods of unfavorable conditions. It is comparable to hibernation and the drying of sap in trees.

Recovery from the rest period merely involves gradual restoration of heat and moisture. Similar recovery can be observed in flies which have become stiffened during the wintertime. These can often be swept from the ceilings and corners without arousing any signs of activity, but by applying heat gradually, the legs will begin to wriggle again. Rotifers have been kept in a dried condition in bottles for months, and brought to renewed activity again. Frogs can even withstand freezing for a short time, and recover.

It is not in the actual activity, therefore, that the presence of life is indicated, but in the potentiality, which often defies detection. It is the extreme conditions of rest afforded by spore formation which offset the occasional excessive activities of the bacteria.

ACTIVITIES

The importance of the bacteria lies in their activities rather than in their structure, and many are known by their activities alone. According to their nutrition, they can be divided into *autotrophes* and *heterotrophes*. The latter group is further subdivided into *saprophytes* and *parasites*. According to their respiratory habits, they are called *aerobes* or *anaerobes*. Aerobes require the presence of free oxygen for the release of energy. Anaerobes can release energy from the oxidation of inorganic compounds. *Strict,* or *obligate,* anaerobes can exist only in the complete absence of oxygen; *facultative* anaerobes are anaerobic under certain conditions but can utilize free oxygen if it is available.

The oxidation-reduction processes in bacterial metabolism include all the types described in Chapter XII. In this elementary introduction to bacteria the chemical details are not completely covered. Students are referred to standard textbooks of bacteriology for more information.

Secretion.—It is because the by-products of bacterial metabolism are found in the surrounding medium that they are of extreme value to mankind as well as being man's most dangerous enemies. Among the secretions of bacteria are the *gelatinous* substances which hold the cells together, the *chitin* deposited in the capsule walls, *pigments, enzymes* and *toxins*. These last-named secretions may be found both inside and outside the cell.

Toxins.—If toxins are secreted into the surrounding medium, they will be poisonous to other organisms. The organism harboring a parasite is called a *host*. It is the toxins which cause disease in the tissues of the host. Such a toxin as that secreted by the tetanus parasite produces the violent symptoms of lockjaw. This toxin is two hundred times as virulent as arsenic and forty times as virulent as rattlesnake venom.

Toxins which are retained within the cell are toxic only after the death of the parasite. These are called *endotoxins.* The typhoid bacillus secretes this type of toxin.

Toxins which lose their toxicity but retain their antitoxic power are called *toxoids.* Toxoids are used in protection against disease as in diphtheria.

There are toxic substances among the by-products of anaerobic protein decomposition which are toxic to the host but are not true toxins. These are called *ptomaines.* They are not secreted by the bacteria but they are caused by their activities.

FERMENTATION

Fermentation is a term applied to all the intermediate by-products of metabolism which are activated by enzymes. In bacteria these are found outside the cell, and many of them are useful in commerce. It is a form of external digestion from which the necessary molecules can be absorbed by the cell and the unnecessary products discarded. It is the host or the substance invaded that makes use of the by-products. Each type of fermentation has a specific bacterial species to activate it, for enzyme action is specific and each species secretes a different kind.

Decay.—An aerobic fermentation of proteins. It has characteristic but not offensive odors.

Putrefaction.—An anaerobic fermentation of proteins. In the hydrolysis of proteins, successive stages are passed. When amino acids have been formed, bacteria may further hydrolyze them to produce ammonia, hydrogen sulphide, marsh gas, etc. This frequently occurs in the lower intestines. It has characteristic offensive odors.

Alcoholic Fermentation.—This is the fermentation of sugars with the formation of alcohol as a by-product. It can be accomplished by a few species of bacteria, although by far the most active agents are the yeasts.

Yeasts are one-celled colorless plants belonging to the Fungi. They differ from the bacteria in that they reproduce by budding, and that the enzyme, zymase, is not secreted into the surrounding medium but is retained within the cell.

As alcoholic fermentation is a commercially valuable process, starches must often be used. These cannot be attacked by the enzymes until changed to sugars. This is accomplished by allowing the starch grains to germinate with the formation of diastase which will digest the starches to sugars, after which fermentation may be induced.

$$\underset{\text{(sugar)}}{C_6H_{12}O_6} + \underset{\text{or yeast}}{\text{bacteria}} = \underset{\text{(alcohol)}}{2C_2H_5OH} + \underset{\text{(carbon dioxide)}}{2CO_2}$$

Acetic Acid Fermentation.—Further fermentation of alcohol into acetic acid can be accomplished under favorable conditions by the acetic acid bacteria. This will occur only when the alcohol has become sufficiently concentrated to kill or inactivate the bacteria or yeast.

$$\underset{\text{(alcohol)}}{C_2H_5OH} + \underset{\text{(oxygen)}}{O_2} + \text{acetic acid bacteria} = \underset{\text{(acetic acid)}}{HC_2H_3O_2} + \underset{\text{(water)}}{H_2O}$$

This can be further oxidized to produce carbon dioxide and water.

$$\underset{\text{(acetic acid)}}{HC_2H_3O_2} + \underset{\text{(oxygen)}}{2O_2} + \text{bacteria} = \underset{\text{(carbon dioxide)}}{2CO_2} + \underset{\text{(water)}}{2H_2O}$$

Acetic acid fermentation is utilized in the making of vinegar from apple juice and in the manufacture of wines. The so-called "mother" which forms like a scum on the surface contains a variety of bacteria, so that the processes involved are doubtless multiple, no one organism sufficing.

Lactic Acid Fermentation.—The fermentation of milk sugar to form lactic acid. The process is similar to acetic acid fermentation; it results in the coagulation of the casein, forming the curd of the milk, and causes the milk to sour.

Although this process is a nuisance to the housekeeper, it is of great importance in the making of butter and sour milk cheeses. The characteristic flavors and odors are due to the specific types of bacteria dominating in the reactions.

Other Activities.—Bacteria break down the cell walls in plant and animal tissues. The indigestible cellulose is thus made soft and pliable for egestion, and the tendons and tough membranes of muscles may be broken down, thus assuring tender beefsteak. Somewhat similar is the process called "retting," by which the bast fibers of hemp and flax are freed from the cementing material which holds them fast to other tissues. The bast fibers are used in the manufacture of linen threads.

The tanning of hides, and the curing of tobacco are also dependent upon bacterial activity.

Chemotrophic Bacteria.—The activities of the chemotrophic bacteria are responsible for maintaining the balance between animal and plant life. Their nutrition is chemosynthetic for they utilize the inorganic decomposition products of plant and animal protoplasm, and so rescue for the organic world what would otherwise be unavailable. The most familiar forms are the nitrogen and sulphur bacteria.

The growth of green plants depends upon the supply of nitrogen, sulphur, and phosphorus in the soil. These are absorbed by the root hairs in soluble form, and, except in rare cases, the plant can absorb them only in the form of nitrates, sulphates, and phosphates. Bacterial activity is essential in the transformation of nitrogen compounds to nitrates, is usually essential in the transformation of sulphur compounds to sulphates, and frequently functions in a similar way in forming phosphates.

Nitrification.—Ammonia is formed as a decomposition product during the fermentation of proteins. In the transformation of the ammonia to nitrates several steps are necessary.

1. By the activities of Nitrosomonas, a chemotrophic bacterial type, the ammonia is oxidized to nitrous acid.

$$2\,NH_3 \text{ (ammonia)} + 3\,O_2 \rightarrow 2\,HNO_2 \text{ (nitrous acid)} + 2\,H_2O.$$

2. The nitrous acid combines with bases in the soil to form nitrites.

HNO_2 (nitrous acid) + NaOH (sodium hydroxide) → $NaNO_2$ (sodium nitrite) + H_2O.

3. Another species, Nitrobacter, causes further oxidation of the nitrites to nitric acid.

2 HNO_2 (nitrous acid) + O_2 → 2 HNO_3 (nitric acid).

4. The nitric acid combines with bases in the soil to form nitrates.

HNO_3 (nitric acid) + NaOH (sodium hydroxide) → $NaNO_3$ (sodium nitrate) + H_2O.

Similar steps occur when the sulphur or phosphorus compounds are transformed by bacterial action, different species functioning in each case.

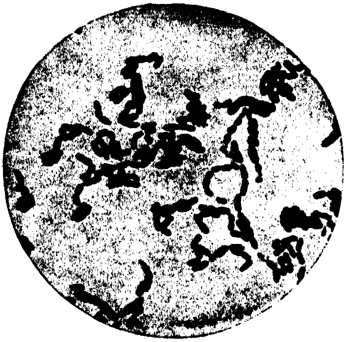

Fig. 79.—Azotobacter. Photomicrograph of a large nitrogen-fixing species. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

Denitrification.—Certain bacteria cause a reverse process, releasing free nitrogen from nitrates by forming first nitrites, then ammonia, and then splitting off the nitrogen molecule. Either the ammonia or the nitrogen molecule may pass off into the air where they are unavailable to green plants.

Nitrogen Fixation.—The nitrogen of the atmosphere can be returned to the soil by the activities of the nitrogen-fixing bacteria. Some of these live freely in the soil, but many live in the nodules on the roots of leguminous plants, such as peas, beans, clover, alfalfa, etc. The leguminous plants are frequently used by farmers, therefore, in alternation with other crop plants, and the supply of nitrogen in the soil may thus be kept fairly uniform.

Nitrogen fixation may also be induced artificially by electricity. By this method much greater quantities of nitrogen can be captured for plant use than could possibly be accomplished in the same time by the nitrogen-fixing bacteria. For this reason the electrification of atmospheric nitrogen has become an important commercial enterprise.

Unicellular Animals

The unicellular animals belong to the Protozoa, but no hard and fast distinction divides them from the Protophyta (one-celled plants). True holozoic nutrition is established in the majority, but many mixotrophic flagellates suggest the origin of the animal forms from the algae. Many specializations have been developed, and thousands of species are known. There is a general uniformity, however, in the motile elements, of which there are but three. It is probable that all three are expressions of the contractility of protoplasm, although there is some question as to the rôle of contractility in pseudopodial formation.

Flagellum.—The flagellum is a whiplike prolongation of the protoplasm. It consists typically of an axial filament extending into the endoplasm where it arises from a kinetic center, and is surrounded by an ectoplasmic sheath. In the bacteria only the sheath is present, no filament being formed. The kinetic center may be a *basal granule,* or may be contained in a basal body. Frequently there is a second parabasal body. The basal body is a *blepharoplast.*

Cilia.—The cilia are similar to flagella except that they are very short and delicate. Each has an ectoplasmic sheath and an axial filament arising from a basal body. Motion is accomplished by the synchronous contractions of large numbers of cilia, and, while individually less powerful than flagella, collectively they accomplish the most rapid type of motion of which unicellular organisms are capable.

Pseudopodium.—While apparently the most simple type of locomotion, pseudopodial motion is probably the most complex of the three. Movement is accomplished by the flowing of the protoplasm forward, and the drawing in of the posterior end toward the pseudopodium. As the motile element is temporary, being formed wherever needed, the term "*pseudopodium*" (false foot), is applied to the portion of the organism which is projected forward.

During recent years pseudopodial motion has been the subject of much controversy, and the questions raised have not yet been satisfactorily settled. Amoeba has been used almost exclusively in the investigations. Several theories have been devised to explain the process, with the general result that it is no longer looked upon as the most primitive type of locomotion.

As described by Chambers there are five phases to the process:

1. A protrusion of the pellicle with a liquefying of the granular ectoplasm directly beneath it.
2. The liquefied ectoplasm and endoplasm flow into the extrusion.
3. The posterior end of the Amoeba diminishes in size, and tends to be drawn in toward the pseudopodium. It is relatively solid.
4. The endoplasm streams to the tip of the pseudopodium where it spreads and flows back as a peripheral current. The backflow is normally arrested on meeting the more solid portions.
5. The pellicle moves forward on the free surface of the pseudopodium, but it is stationary where the pseudopodium adheres to the substratum.

During the process an anteroposterior viscosity gradient is established. It is probable that contraction, surface tension, viscosity changes, and adherence—all play a part in the phenomenon, and that no one process alone can explain it.

The terminology of the motile element is confused, since botanists and zoologists have never agreed on the use of terms. In botanical literature, therefore, the term "cilia" is used for the motile elements of the swimming gametes. There is little doubt of the homology between these and the flagella of the Protozoa.

The Protozoa are divided into classes according to the type of locomotion predominant in the group. The *flagellum* is considered the primitive one, and is found in the bacteria, some plant forms, and many of the mixotrophic organisms. The cilia are doubtless modified flagella, and the pseudopodia may also have been a derivation of the flagella through the radiating pseudopodial types. Many organisms have both pseudopodial formation and locomotion by flagella, and in some life cycles the two elements alternate.

A fourth group of the Protozoa, the Sporozoa, combines the methods of locomotion to such an extent that their classification is based upon their parasitic life, rather than upon their locomotion.

The classes are as follows:

Class Mastigophora: Flagellated forms (flagellates).
Class Infusoria: Ciliated forms (ciliates).
Class Sarcodina: Pseudopodial forms (rhizopods).
Class Sporozoa: Parasitic forms.

In the Mastigophora, all types of nutrition are found, even the mixotrophic where two or more kinds are combined. In the other groups of the protozoa nutrition is entirely holozoic. The Mastigophora is therefore, the primitive group.

A Rhizopod

A Holozoic Type

Amoeba Proteus

The Amoeba is an animal organism with pseudopodial locomotion. Long considered the most primitive animal type, it has become a classic in biologic literature, but the probability is that the Amoeba represents a highly specialized group and that pseudopodial locomotion has been derived from the flagellated type.

Amoeba still remains a favorite in the laboratory, however, since its simplicity and formlessness illustrate more aptly than any other type the nature of unspecialized protoplasm.

It is a transparent cell with a central granular mass, surrounded by a clear hyaline area. The inner part of the granular mass is more liquid than the outer, and constitutes the endoplasm. The outer granular mass is probably contractile.

With the liquid, hyaline zone it forms the ectoplasm around which is stretched a thin, tenuous pellicle. The presence of the pellicle has been demonstrated by the microdissection method. It can be lifted off if water be injected beneath it.

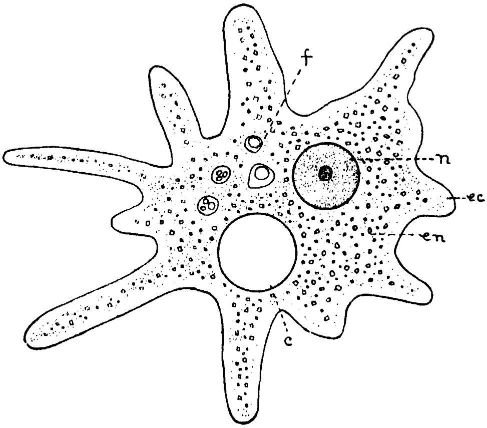

Fig. 80.—*Amoeba proteus.* *f*, Food vacuole; *n*, nucleus; *ec*, ectoplasm; *en*, endoplasm; *c*, contractile vacuole.

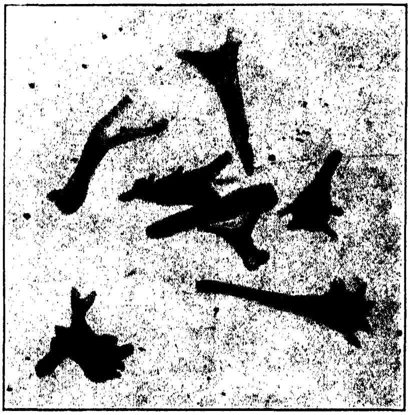

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Fig. 81.—*Amoeba proteus* shown in various forms assumed in pseudopodial locomotion. (Photomicrograph by Albert E. Galigher.)

The organism is amorphic, or formless, since it is continually changing in shape by pseudopodial formation. In the granular endoplasm are protoplasmic currents in which the nucleus and contractile vacuole move freely.

Nutrition is strictly holozoic. The food vacuoles are temporary structures, as is also the anal spot, the solid wastes being pinched off wherever they happen to collect. No other fixed protoplasmic structures appear, and there is no specialized apparatus of any kind. Thus the vital functions of the animal are here demonstrated as inherent functions of the protoplasm.

Behavior.—The one response to all stimuli is pseudopodial formation. The protoplasm is very sensitive to food; the pseudopodia flow around the food on all sides until it is engulfed in the protoplasm. The food consists of minute plants, algae and diatoms. Often whole filaments are ingested, and the cell becomes so gorged with food that it can no longer move about. Digestion proceeds in food vacuoles which form less quickly than in Paramecium, but which have the same history. Nothing is known of the specific enzymes formed.

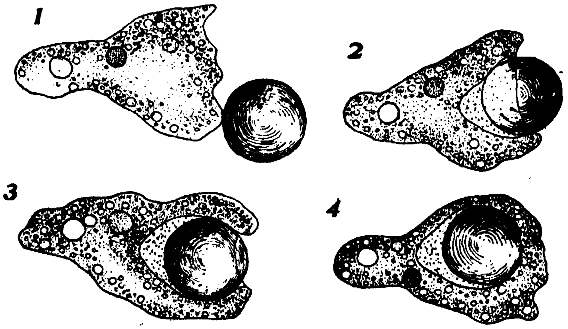

Fig. 82.—Amoeba ingesting a Euglena cyst. (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

Reactions are adaptive in Amoeba, for, while the organism is negatively phototropic, it becomes adapted to light. This can be demonstrated more easily in an Amoeba than in rapidly moving forms. The first reaction to a strong white light is the cessation of all movement. If the light continues, however, the Amoeba will gradually resume motion, and will show no further response to increase in the stimulus. A change has taken place in the physiologic state which has adapted the protoplasm to light. In the same way Amoeba can be adapted to tap water which would be injurious if applied directly.

Flagellates

A SAPROZOIC TYPE

PERANEMA

Peranema is a colorless flagellate with entirely saprozoic nutrition. It absorbs the dissolved proteins formed by the digestive activities of bacteria, and since these are formed outside the bacterial cell, the Peranema is not a parasite.

There is a single flagellum directed forward, but it hardly seems to move because the movement is restricted to the tip end of the whip. The flagellum extends out from a *basal* body which in turn is connected by a fine thread to a longer parabasal body, extending some distance into the cell. It is not easily seen in the living organism but can be brought out by fixation with iodine.

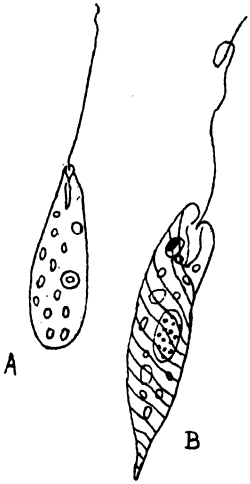

Fig. 83.—*A*, Peranema; *B*, Euglena.

Peranema is a small, colorless cell with a nucleus and a contractile vacuole. Division is in the longitudinal plane which is typical of the flagellates.

A MIXOTROPHIC TYPE

EUGLENA

Euglena is a mixotrophic flagellate with saprozoic and autotrophic nutrition of the photosynthetic type. The green color is due to *chloroplastids* in the cell, containing chlorophyll bodies. Photosynthesis is carried on as in all green plants and the starch, which differs in form from the typical plant starch, is deposited in *paramylum* bodies. Dissolved proteins are absorbed from the water through the cell wall.

The flagellum is a whiplike process, not unlike an elongated cilium. In Euglena there is a single flagellum which is directed forward, and which makes a wide sweep in the water. At the anterior end is a red eyespot which is sensitive to light.

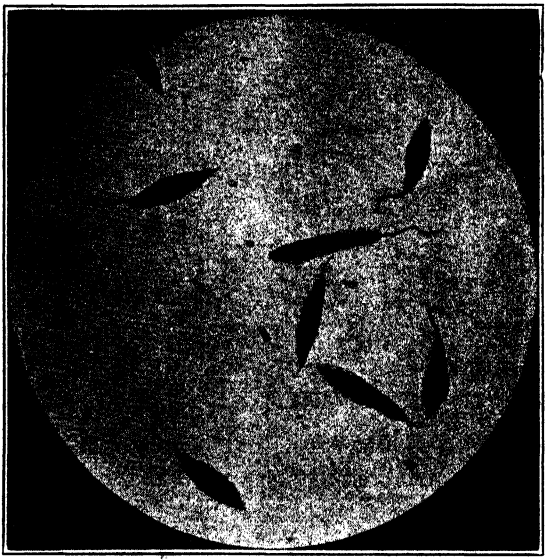

Fig. 84.—*Euglena viridis,* shown with flagellum extended. (Photomicrograph by Albert E. Galigher.)

Some observers have described a lenslike body in connection with the eyespot, and have ascribed a directive function to it. The spot is always turned toward the light during locomotion, the cell rotating as necessary to maintain the position. This is one of the earliest differentiations in protoplasm for the receipt of a definite stimulus.

Unicellular Plants

Strictly one-celled green plants without colony formation are not numerous, since the tendency to form colonies developed earlier in the plants than in the animals. Even in the more solitary types, gelatinous secretions often hold the cells together after division.

TWO HOLOPHYTIC TYPES

SYNECHOCOCCUS

Synechococcus is a solitary blue-green alga. The blue-greens are the simplest of the plants which make their own food by photosynthesis. The chlorophyll is spread diffusely throughout the outer layer of protoplasm which surrounds a clear inner layer. The blue-green appearance is due to a second pigment, phycocyanin, which is present with the chlorophyll. This has doubtless some part to play in the making of food, but its exact function is uncertain.

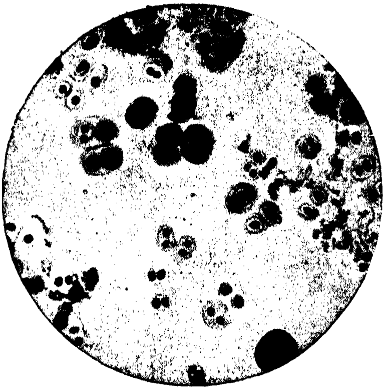

Fig. 85.—Gloeocapsa. Photomicrograph showing the cells held together in a gelatinous matrix. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

The inner layer of clear protoplasm is not separated from the outer by a plasma membrane, and no nucleus is thus formed. The chromatin granules may be aggregated in clumps or scattered.

The starch which is made is not of the plant type, but glycogen, a form of starch stored in animal tissues, and found in some fungi.

Gloeocapsa is a single-celled form also, but gelatinous secretions hold the cells together after fission (Fig. 85).

PROTOCOCCUS

Protococcus is a typical one-celled green plant. It has fully established photosynthesis with formed chloroplasts, and a definite nucleus. Even here the cells often remain in contact after division, and the cell walls are flattened where they come in contact.

Groups of two and four cells are frequently seen, and occasionally more. No resting spores are formed, since the cell wall is very heavy and is sufficiently resistant to drying.

Protococcus is a semiterrestrial form, and is found on damp surfaces of rocks and trees. So consistently does it cling to the damp areas that in certain regions it may act as a compass, a layer of Protococcus indicating the north side of a tree. This side is less directly exposed to the drying rays of the sun and is, therefore, persistently damp.

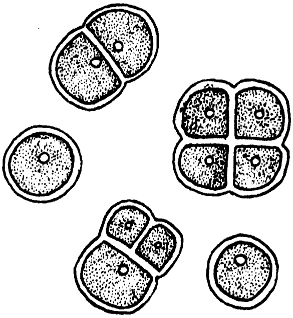

Fig. 86.—Protococcus. The nuclei were made visible with formaldehyde.

DIVISION OF LABOR

In the unicellular groups there has been some tendency to economize by the distribution of functions between cells. Especially has this been true in colonial forms, but in the unicellular animals the first expression of division of labor has been between the sexual and asexual cells of the life cycle.

Development which involves the alternation of asexual and sexual forms in the completion of a life cycle is known as *alternation* of *generations.* True alternation exists only when there is a well-defined difference in structure between the sexual and the asexual individual.

True alternation was established later in the plant kingdom than in the animal kingdom, but was retained throughout the entire development. The unicellular animals established an alternation, but it is found only spasmodically in the Metazoa. It is probable, therefore, that the development of the tissue plants from the protophyta was an earlier one than that of the Metazoa from the Protozoa.

The life cycle of Paramecium described in Chapter VIII is an example of a life cycle without true alternation, since the participating organisms are exactly alike.

The terminology in plants and animals is not similar throughout, but certain terms are used for both.

1. Gametes—the specialized cells which fuse in fertilization.
   a. Macrogamete (egg), inactive gamete to be fertilized.
   b. Microgamete (sperm), motile element destined to fertilize the macrogamete.
2. Zygote—the fertilized or fusion cell.
3. Isogamy—a life cycle in which the gametes are of equal size and form.
4. Heterogamy—a life cycle in which the gametes differ in size or form.
5. Conjugation—union of like gametes.
6. Fertilization—union of unlike gametes.

An Isogamous Animal Form

A HOLOZOIC TYPE

POLYSTOMELLA

Polystomella is one of the pore-bearing rhizopods, known as the Foraminifera. These animals live in the ooze on the ocean floor, and secrete minute chalky shells which coil and form chambers. The pseudopodia radiate out through the holes of the shell, and then flow together to form an irregular mass of protoplasm about the shell. This process is known as anastomosis.

As the shell of the asexual individual contains but one chamber, it is called microspheric. Inside this shell the nucleus divides into twenty-eight parts, after which the protoplasm is withdrawn into the shell and divided into as many parts, each one with a nucleus. The individuals formed by this multiple division have an amoeboid form and escape through the pores of the shell by pseudopodial motion. Each ultimately secretes a shell with many chambers, the macrospheric shell, which thus differs structurally from the asexual form. This is true alternation.

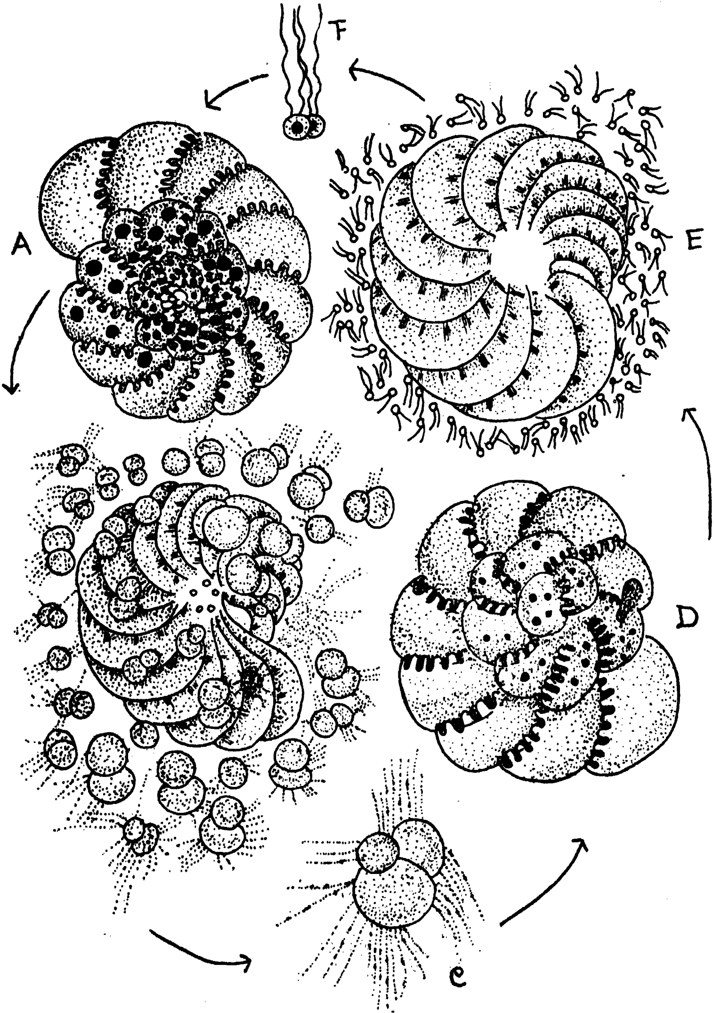

Fig. 87.—Life cycle of *Polystomella crispa*. *A*, Microspheric individual; *B*, amoeboid cells escaping from it; *C*, young macrospheric individual developing from amoeboid cell; *D*, macrospheric individual; *E*, flagellated gametes escaping from it; *F*, union of gametes. (From Lang, after Schaudinn.) (Redrawn from Parker and Haswell: Zoology. By permission, The Macmillan Co.)

The cell in the macrospheric shell enlarges and wanders about from chamber to chamber, the nucleus finally breaking into innumerable minute parts. The protoplasm then divides into fragments, and minute, flagellated cells are formed, each with one nucleus.

These are the gametes, and are all alike. They escape through the pores and fuse in pairs to form the zygote which secretes the microspheric shell.

An Isogamous Plant Form

A HOLOPHYTIC TYPE

CHLAMYDOMONAS

Chlamydomonas is one of the simpler one-celled green algae in which the cells tend to remain together temporarily but escape eventually. It is found in moist soil, in ditches and pools. The cell wall is rigid and contains cellulose. The cell is ovoid in shape, narrowing toward the anterior end. The single, large, cup-shaped chloroplast occupies most of the cell. It is thin at the narrow end, thickening toward the wide end, so as to form a very thick base in the center of which a small colorless *pyrenoid* will be found. This functions in the final steps of photosynthesis by instigating the transformation of sugar into starch. Usually the pyrenoid itself is obscured by the starch granules which surround it.

Toward the anterior end is a minute reddish orange eyespot which is sensitive to light, and so directs the movements of the cell. Locomotion is accomplished by two long cytoplasmic threads extending from the anterior end. These are called *cilia.* At the base of the cilia are the small contractile vacuoles. There are usually two, but more may appear.

The center of the chloroplast is filled with cytoplasm which has a definite nucleus. This is surrounded by a plasma membrane, and contains a nucleolus and chromatin granules on a linin network.

When the cells divide, the plasma membrane constricts inside the cell wall so that four, and sometimes eight, daughter cells are formed inside the parent wall. These later form their own cell walls and escape to repeat the process. Occasionally, however, the cells do not escape, but continue to multiply within the parent wall, in which case the wall becomes gelatinous and expands to accommodate a large colony. Even these cells eventually escape.

A primitive sexual union of the isogamous plant type occurs when conditions prove unfavorable. It differs from the asexual reproduction only in the smaller size of the cells which function as gametes. There are usually thirty-two or sixty-four of these. They unite in pairs, and the protoplasm then escapes from the two cell walls which are left behind. The two naked cells then unite and secrete an especially hard and resistant wall, which will preserve the zygote over long unfavorable periods. Within the zygote wall the nuclei unite, and all the other visible ele-

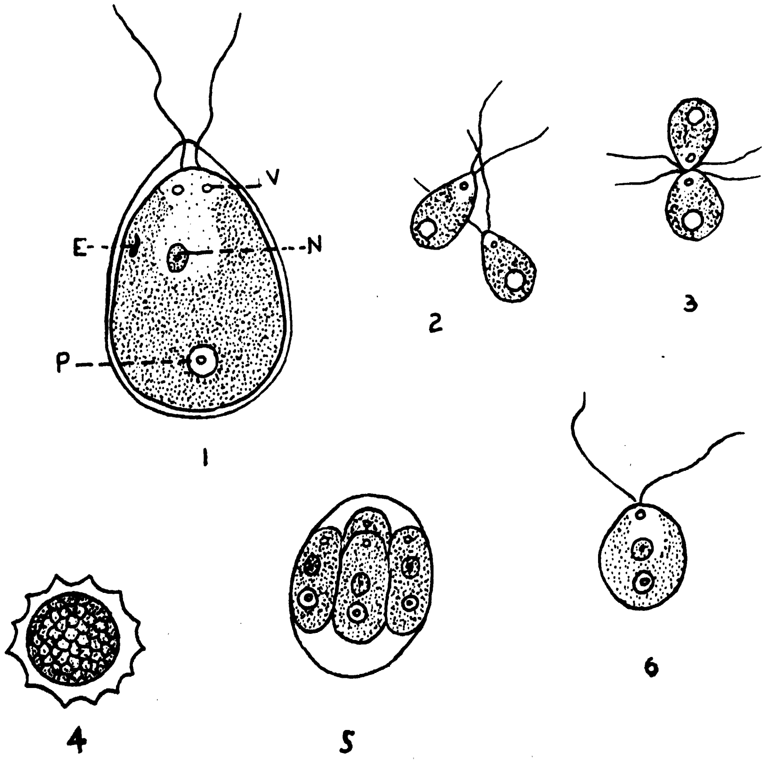

Fig. 88.—Chlamydomonas. *1,* Mature individual; *E,* eyespot; *N,* nucleus; *P,* pyrenoid; *V,* contractile vacuole; *2,* gametes; *3,* gametes uniting; *4,* zygote; *5,* zygote forming zoospores; *6,* a zoospore.

ments of the two cells become indistinguishable. The contents then become oily and have a red color.

When conditions permit germination, the green color returns and daughter cells are formed within the zygote wall. These develop cell walls, cilia, chloroplasts, pyrenoids, and eyespots, and finally escape from the zygote wall.

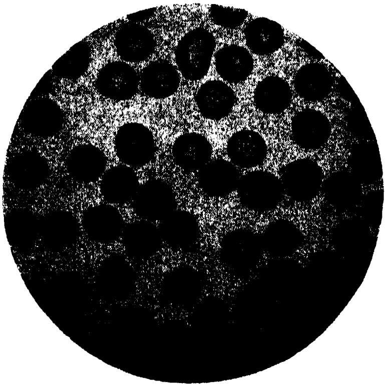

Fig. 89.—*Plasmodium vivax.* Parasite of tertian malaria in human blood corpuscles. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

A Heterogamous Animal Form

A SAPROZOIC TYPE

PLASMODIUM

Plasmodium is the malarial parasite, and belongs to the parasitic group, Sporozoa. This form has not only true alternation, but alternation of hosts as well.

The asexual individuals are called sporozoites. These live and multiply in the blood corpuscles of man. The sexual individuals are formed in the blood of man, but cannot complete the life cycle except in the stomach of an Anopheles mosquito.

It takes a definite length of time for the sporozoites to fill a corpuscle. This they do by growth and fragmentation. The bursting of the corpuscles is accompanied by the vibrations, or chills, which are typical of malaria. These occur every three days in the species *Plasmodium vivax,* every four days in the species *Plasmodium malariae,* which produces quartan fever, and every twenty-four hours in *Plasmodium falciparum,* the species of estivo-autumnal malaria. The chills are followed by a fever caused by the secretion of the melanin granules which escape with the parasites into the blood.

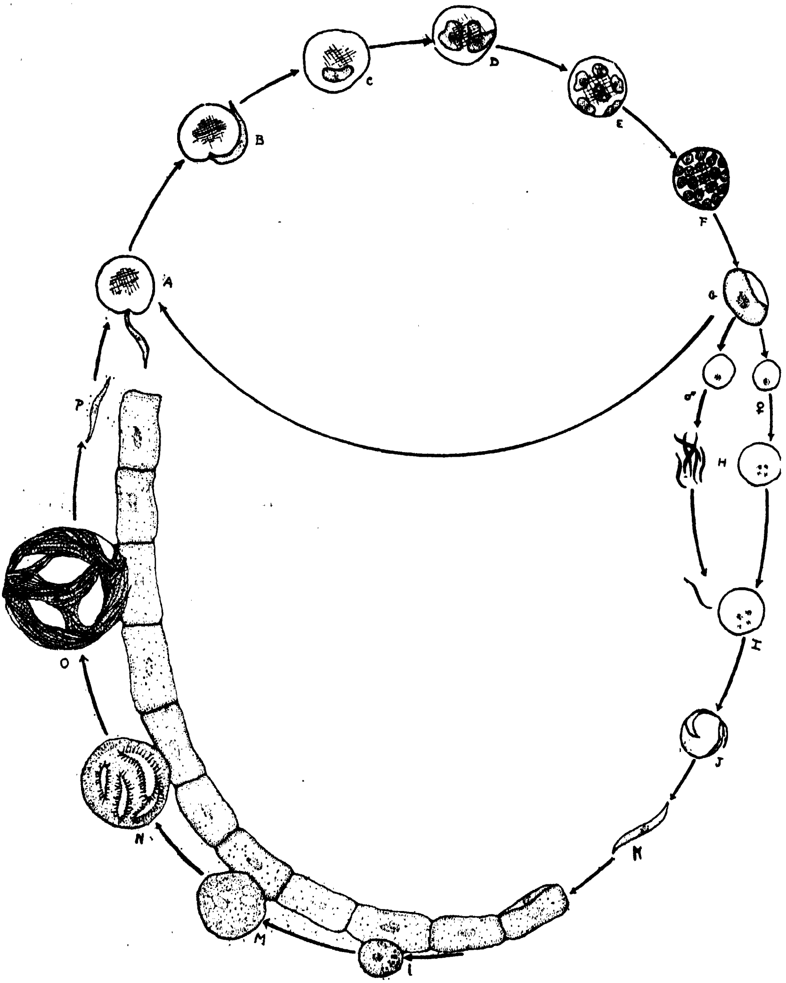

Fig. 90.—Life cycle of the malarial parasite. *A* to *F*, Asexual stage in the blood of man. The sporozoite enters and fills a blood corpuscle by multiplication. *G* to *H*, Stages in the formation of the male and female gametes. *I* to *P* in the mosquito. *I*, Fertilization; *J* and *K*, penetration of the stomach wall; *L, M, N,* and ~~*O*,~~ development of sporozoites in the oocyst; *P*, mature sporozoite which enters salivary gland of mosquito from which it may be transferred to man.

As the younger organisms are specifically sensitive to quinine, the application of this remedy may kill them. Other less dangerous chemicals have been developed during World War II and used extensively in the treatment of malaria. Atabrine has been used with considerable success, and new chemicals are still coming on the market. It is to be hoped that some wholly effective cure may be found, for malaria ranks with malnutrition as the great destroyer of productive energy in our southland. Five million people are infected every year, even with our knowledge of mosquito control. The economic loss is estimated at not less than $1,000,000 each year. If they persist, sexual individuals will be formed which differ greatly in size—the macrogametes and the microgametes. In the event of a mosquito sucking the blood of the victim, these cells will complete their cycle, otherwise they will perish. In the stomach of the mosquito the cells unite (true heterogamy), and will bore into the epithelial lining. There the zygote divides until many sporozoites are formed, which swim to the salivary glands and are deposited through the proboscis of the mosquito into the blood of the next man attacked.

COLONY FORMATION

There is a general tendency among the various unicellular groups for cells to become associated together in more or less permanent colonies. The colonies may frequently simulate tissue formation, but they differ from the tissues of higher animals and plants in the complete independence of each cell, even as one Paramecium is independent of any other.

The colonies may be united by protoplasmic threads, by stalk attachments, or by fixation in a gelatinous matrix. They may be free-swimming, floating, or attached (sessile). They may be permanent or temporary, and may be formed by the adherence of cells after division, or by the aggregation of previously separated cells.

Several types of aggregation are formed.

1. **Linear colonies.**—Repeated cell division in one plane. Example—Nostoc. Aggregation of previously separated cells into a linear series. Example—Streptococci.

2. **Branching colonies.**—Cells attached by contractile stalks. These may be separately attached at the base. Example—Vorticella. They may branch to form treelike colonies. Example—Codosiga.

3. **Spherical colonies.**—Cells arranged in a superficial layer and enclosed in a gelatinous matrix. Such colonies may have stalks which attach the individual cells to a common center. Example—Synura. They may be free from stalks. Example—Volvox. Solid spheres also occur. Example—Pandorina. Flat plates may be a variation of the sphere. Example—Gonium.

4. **Irregular colonies.**—Cells loosely joined together in a gelatinous matrix. Example—Proterospongia.

Plants in general develop tissues by linear aggregation; animals, by spherical. It is probable, therefore, that the higher plants were derived from linear colonies, and the main animal line from spherical ones; although, in the latter case, true connecting forms are lacking, since the spherical colonies in general are mixotrophic forms, and it is supposed that the holozoic nutrition had become established before the development of tissues took place.

The sponges had a separate origin, and are so similar to the group of flagellates with protoplasmic collars (Choanoflagellata) that, except for the fact that there is a loose arrangement of cells into two layers, they might almost be considered choanoflagellate colonies. The colonies of the choanoflagellates are irregular in form, and the cells are held loosely in a gelatinous matrix.

The sponges mark the end of a line, all higher animals having been derived from the coelenterate type.

A Spherical Colony

With Heterogamy

A Mixotrophic Type

Volvox

The spherical matrix of the flagellate, Volvox, is a permanent structure, and the cells are connected by strands of protoplasm which give the surface of the colony the appearance of a tissue. There are three distinct modifications, a more complete division of labor than found in the other unicellular groups. The surface cells are small and have a vegetative function, with mixotrophic nutrition, photosynthesis, and saprozoic nutrition combined. A few large cells are set aside for the asexual reproduction of the colony, and still other cells as gametes.

The large cells are called parthenogonidia. When they divide, they form hollow balls which sink into the center of the sphere. There they continue to multiply until a daughter colony, similar in all respects to the parent colony, is formed. These daughter colonies escape by rupture of the wall and repeat the asexual activities.

When the sexual phase occurs, certain of the cells divide transversely, the ordinary method being longitudinal, as in other flagellates. The cells so formed migrate into the cavity and there differentiate into male and female gametes. The microgametes are the spermatozoa, and are provided with flagella for locomotion; the macrogametes are the egg cells which are large and inactive. Fertilization is accomplished within the cavity of the colony, and a new colony is formed which, as in the case of the daughter colonies, escapes by rupturing the wall. Rupture of the wall kills the parent colony, so that, unlike the Paramecium, the parent organism is not absorbed into the child.

A Linear Colony

A HOLOPHYTIC TYPE

NOSTOC

Linear colonies are occasionally formed by the one-celled animals but are much more typical of plants. Nostoc is one of the blue-green algae, similar in structure to Synechococcus, but the cells divide so as to form a linear series of cells which are held together by gelatinous secretions, making it possible for the colonies to attain a considerable length.

The cells are rounded. In Oscillatoria, a related species, the cells are flattened, and the colonies are held together in a matrix but have a peculiar swaying motion by which they accomplish a sort of locomotion in the water.

Such colonies may reproduce asexually by the breaking up of the filaments. At intervals in the colonies of Nostoc large colorless cells may appear. They are called *heterocysts,* and the filaments break at these points. The short filaments which have broken off are called *hormogonia.*

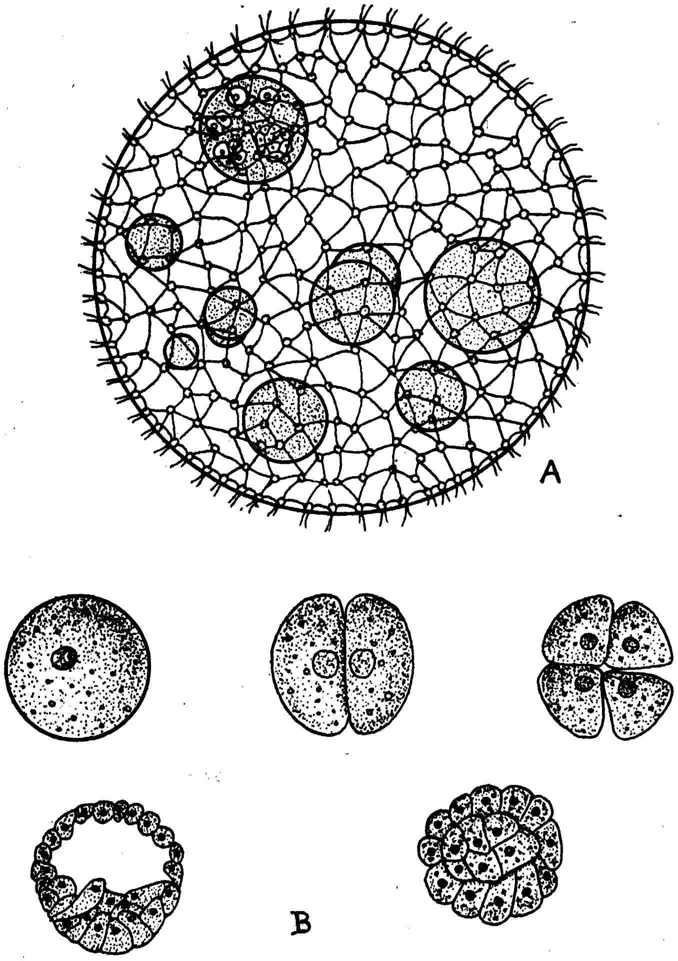

Fig. 91.—Volvox. *A,* Mature colony containing several daughter colonies in various stages of development. *B,* Stages in the development of a parthenogonidium to form a daughter colony. This is the asexual stage.

They creep out of the gelatinous mass and reproduce the colony. In Oscillatoria no heterocysts form, but dead cells occur throughout the colony and the filaments break where they appear.

Resting spores are formed by the increase of a normal cell to accumulate a reserve food supply. These are very resistant to drying, and will develop new colonies only when conditions are favorable.

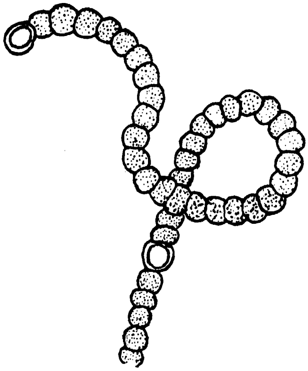

Fig. 92.—Nostoc. Filament showing vegetative cells and heterocysts.

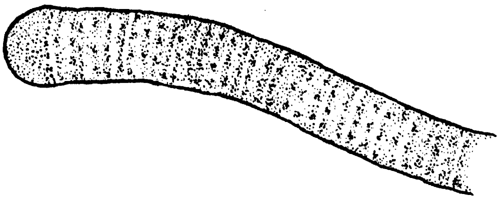

Fig. 93.—Oscillatoria.

A Linear Colony

With Isogamy

A HOLOPHYTIC TYPE

SPIROGYRA

Spirogyra is one of the more common pond scums, familiar in stagnant pools. The cylindrical filaments are linear colonies of cells. They are bright green in color and occur in gelatinous masses which are slippery to the touch, because of the gelatinous layer in the outer walls. They usually float freely on the surface of the water.

Asexual Stage.—The apical cell of the cylindrical filament is rounded to form a blunt end. Each cell contains a flat ribbon-like *chloroplast* which is wound spirally about the cell and is dotted regularly with minute colorless pyrenoids. These are connected by a central strand. The spiral chloroplasts give to the plant its brilliant beauty, and from them it has received its name. The cells of a related form, Zygnema, also have attractive chloroplasts which are star-shaped.

The chloroplast in Spirogyra is embedded in the cytoplasm of the cell. The cytoplasm is slimy and is spread about the periphery of the cell in a thin layer around a large central vacuole. In the cavity of the vacuole is the nucleus, surrounded by a fairly dense mass of cytoplasm, from which long strands extend out to the peripheral layer. They join this layer beneath the pyrenoids.

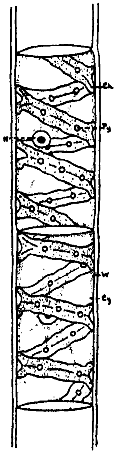

Fig. 94.—Spirogyra. *Ch*, Chloroplast; *Py*, pyrenoid; *N*, nucleus; *W*, cell wall; *Cy*, cytoplasm. (Drawn by Esther Ritter.)

Growth of the filament is accomplished by asexual cell divisions at right angles to the long axis, which result in the linear aggregation of cells characteristic of the unbranched filament. There is no asexual reproduction of the filament, except that by accidental breaking of the filament plants may be multiplied.

Division of the cell is preceded by the division of the central nucleus, and the fission is accomplished by constriction from the periphery. There is no equatorial division plate as in the cells of higher plants.

Sexual Stage.—*Conjugation.*—Sexual reproduction in Spirogyra is accomplished by conjugation. The process occurs at a definite time each year, and is initiated by the arrangement of the filaments in pairs, cells coming to lie side by side.

From two cells lying opposite each other, protuberances appear from the facing walls. These continue to grow until they meet. The contacting walls are digested, so that a continuous tube is formed between the two cells.

The contents of each cell is then a gamete. In one cell the contents will contract from the wall and round up. This is the male gamete. It will migrate through the connecting tube to unite with the female gamete, which, in the meantime, will have contracted from its cell wall and rounded up in preparation for the union.

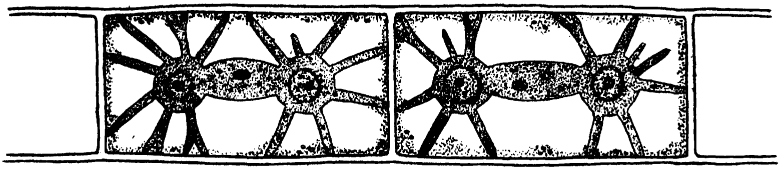

Fig. 95.—Zygnema. Filament showing star-shaped chloroplast.

Although there is a difference in motility between the conjugation gametes, there is no structural differentiation. This is considered, therefore, to be a case of isogamy. Usually all the cells of one filament will be either motile or nonmotile, but in one species of Spirogyra, conjugation is between cells of the same filament.

Before the union of the two gametes is complete, the chloroplasts of both cells can be seen. Eventually, however, the male chloroplast disappears, and the chloroplast of the zygote is apparently formed entirely from the female gamete.

The Spore.—The zygote is a *zygospore* and represents the sporophyte generation of the simple plants. (See page 328.) It forms a thick resistant wall and assumes an orange color. The wall of the filament cell breaks, liberating the zygospore, which sinks to the bottom of the pond. Within the cell, four nuclei form of which three degenerate.

After the resting stage, the heavy outer wall is broken and the green color is restored. The functioning nucleus and chloroplasts of the mature gametophyte are then visible, and a tubelike protuberance grows out from the cell. The nucleus divides and a cell wall forms between two nuclei, separating the cell which extends out of the zygote from the one which remains inside. The outer cell then produces the filament by apical growth, the inner cell dividing no more.

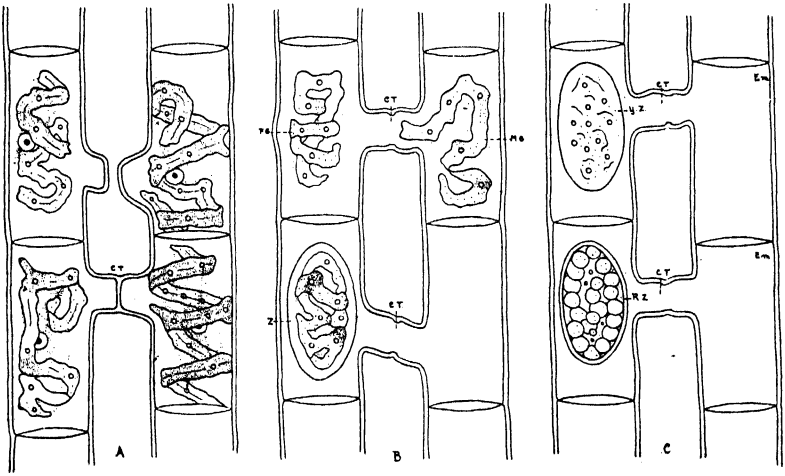

Fig. 96.—Spirogyra. Successive stages in conjugation. *A*, Formation of the conjugation tube, *C.T.* *B*, Union of the gamates. *F.G.*, Female gamete; *M.G.*, male gamete; *Z*, zygote. *C*, Ripening of the zygote. *Y.Z.*, young stage; *R.Z.*, ripe stage. (Drawn by Esther Ritter.)

Affinities of the Unicellular Groups

The relationships shown between the unicellular groups are important because in them we find tendencies toward specialization in different directions—tendencies which are carried on in the higher plants and animals. These then are the roots of the phylogenetic tree of development.

Fig. 97 represents graphically the possible relationships between the groups based on nutritional types. The theory that the chemotrophic type of nutrition antedated all others has been well substantiated, and the bacteria having this type of nutrition are the most logical link with the virus, that half-living molecule that has finally taken its place in the organic scene.

With the pro-gene in view, development is represented following the gradual concentration of chromatin into a nucleus. The steps are outlined below with brief explanations.

1. **The Virus.**—The acceptance of the virus as a half-living molecule is based on two observations.

a. Stanley has demonstrated that viruses will propagate when in contact with living cells and occasionally will mutate into new forms. These are attributes of living cells, specifically of genes.

b. Beutner has crystallized viruses in the pure state. Crystallization is not an attribute of living material but it is a property of nonliving protein molecules.

Some years ago Hurst made the suggestion that the gene was the fundamental living material and that life might have begun as a pro-gene. Genes are protein molecules located in the chromatin granules of the resting cell and lined up in the chromosomes at each cell division. They are self-propagating, for they divide at each mitosis, and they have the power to mutate; since gene mutations are one of the chief causes of species change. Thus Beutner believes that in the virus they have found the pro-gene. The virus then may be chromatin unconfined.

2. **Chemosynthetic Bacteria.**—Structurally the bacteria are the simplest of all living cells. Their chromatin is either scattered in granules throughout the cells or aggregated in clumps. There are no nuclei and no chloroplasts, and except in a few rare species, no indications of chlorophyll.

That bacteria actually existed in point of time before any other type of life has been proved by two investigators.

a. Walcott has identified bacterial formations in Pre-Cambrian rocks of an age antedating all known organic formations.

b. Lipmann has succeeded in bringing to life bacterial spores from the Pre-Cambrian rocks under conditions which, he claims, preclude any possibility of invasion of bacteria from without.

The activities of the chemosynthetic bacteria, especially some of the sulphur and iron bacteria, are independent of all other forms of life and independent of light. They oxidize inorganic compounds and use the energy released for their own metabolic activities, so are independent of free oxygen.

Thus from the point of view of structure, of age, and of nutrition, the chemosynthetic bacteria seem the logical link between the virus and the first photosynthetic cells.

3. **Photosynthetic Bacteria.**—The discovery that a few of the sulphur bacteria do have chlorophyll and that the pigment, *purpurin,* in the purple bacteria absorbs light in a similar manner shows that the assumption of photosynthesis followed the chemosynthetic habit even before organized chloroplasts and nuclei appeared. These bacterial types probably lead directly to the blue-green algae.

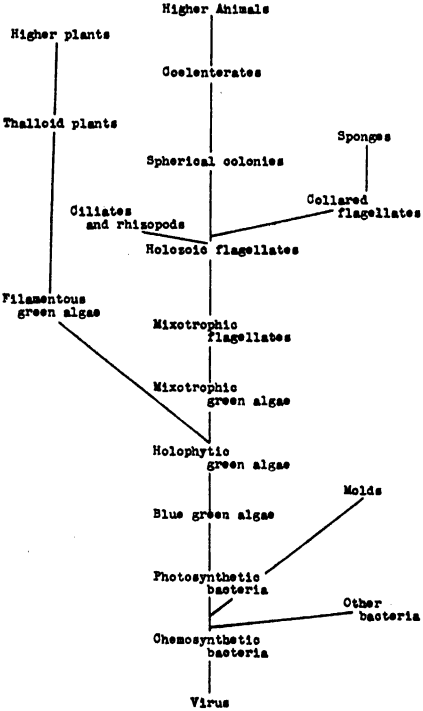

Fig. 97.—Diagram to illustrate the relationships of the unicellular groups.

4. **The Blue-Green Algae** (Cyanophyceae).—The blue-green algae have no organized nuclei. Irregular clumps of chromatin may appear, not much more organized than in the bacteria. The central protoplasm is distinguished from the outer layer by a lack of pigment, although no membrane separates the two. Definite chloroplasts are absent, but chlorophyll is found in the outer

layer. Except that many of the blue-greens tend to form filaments, there is not much advancement over the photosynthetic bacteria.

5. **Green Algae** (Chlorophyceae).—The green algae have well-defined nuclei, with the chromatin material enclosed in a membrane. Definite chloroplasts are present, concentrating the function of photosynthesis. This seems to be the focal point in development from which all higher forms developed. The tendencies are quite definite:

1. An early tendency, established even in some of the blue-green algae, for cells to aggregate in filaments, carried over directly into the thalloid plants and thence to all the higher plants.

2. The tendency for many of the green cells to develop flagella for rapid locomotion probably split off the group of flagellates looked upon as animals. Many of these have adopted a mixed type of nutrition, looking toward the loss of photosynthesis, and the adoption of a more active search for food.

The Mastigophora are looked upon as the most primitive of the Protozoa and from them the other groups, the Ciliates and Rhizopods, developed with holozoic nutrition, the capture of food and digestion.

3. The tendency among the flagellates to develop spherical colonies is also a step toward higher organization. This points to the radial type of animal development found in the coelenterates. These are the simplest of tissue animals and are considered the pivot from which all higher animal development has sprung.

4. The tendency toward development of the sponge type is well defined, also. Holozoic flagellates with protoplasmic collars around the flagella are found among the flagellates and one simple colony form is very similar to sponge tissue. These are the Choanoflagellata.

Sponges have developed a great variety of types, but no higher development in that direction has ever been found. Thus the sponges mark the end of a line of development, which, while successful in itself, was not well adapted to higher development.

CHAPTER X

THE STREAM OF LIFE

Since all life seems to have evolved from the chemosynthetic bacteria, so, also, all life depends on them today, for they form the pivot through which the stream of life flows. This phrase is used to follow the passage of the elements, carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, magnesium, calcium, potassium, and sodium from the plant to the animal and back to the plant again, for nothing is ever lost. The plant takes the inorganic compounds of these elements and synthesizes them into organic food compounds which either plants or animals can use for food. The bacteria split the organic molecules back into inorganic compounds again in a form the plants can utilize. Thus the same elements travel back and forth indefinitely.

Animals enter the cycle by eating the plants either directly or indirectly. The meat served on our tables comes mainly from such animals as cattle and sheep that have eaten grass, or from fowl that have fed on grain. Thus it is true, as Heraclitus once said many centuries ago, ''All flesh is grass.''

Cycles of Nature

The composition of protoplasm is the same in all organisms, and certain elements are in such universal demand for the repair of protoplasm that the supply must be kept at a fairly constant level, for the maintenance of life.

Chief among these elements are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, magnesium, calcium, potassium, and sodium.

The metals are available to green plants only when in the form of nitrates, sulphates, phosphates, and carbonates. The acids necessary to form these salts are largely of organic origin, and the supply is dependent upon other animal or plant life.

Carbon, hydrogen, and oxygen are available to the green plant as carbon dioxide and water, and are taken from the atmosphere. These are also of organic origin, the source of supply being the respiratory processes of animals and plants.

Plants and animals are thus mutually dependent upon each other, and the passage of the elements from one form to another may be represented in a cycle.

THE CARBON CYCLE

Carbon makes up the greatest percentage of the dry weight of any organism. Over half the weight of a dead tree is carbon, because the dead cells have been stored up from year to year instead of being excreted. It is estimated that there is enough carbon in any one adult human body to keep all the plants in the world alive for thirty years, could it be made available for distribution throughout the atmosphere of the world.*

But most of the carbon is not thus available. A great deal of it in the past has been subjected to pressure underground, as in the case of the great fern trees which were buried in the swamp lands during the Carboniferous days, and remain there today, "ages of entrapped sunlight." For in the absence of oxygen, the ordinary disintegration processes were prevented and the hydrogen and oxygen slowly escaped as gases, leaving behind more and more pure carbon as the eras passed. The long-continued pressure of ages completed the process, and, according to the amount and duration of pressure, we find the coal in varying grades of hardness from the soft peat to the hard anthracite.

All carbon is not thus protected from oxidation, and that which is restored to the atmosphere is immediately available to the green plant for photosynthesis. The plant is independent of the animal, having a complete carbon cycle in itself, but the animal is dependent on the green plant for food and oxygen. Only the green plant can capture the energy from the sun and store it in the food. Only the green plant, too, can provide the free oxygen, the only means of releasing the energy in the food. Where green plants cease to live, therefore, there animal life will cease also, and, since green plants receive this energy from the sun, all life in its ultimate analysis is dependent on the sun.

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*Jacobs.

The cycle is represented in the reversible processes of photosynthesis and respiration, or reduction and oxidation. These are reversible processes but cannot be completed in the animal. The formulas given below are condensed to show the reversal, all intermediate steps being omitted.

$$\underset{\text{(carbon dioxide)}}{6CO_2} + \underset{\text{(water)}}{6H_2O} = \underset{\text{(sugar)}}{C_6H_{12}O_6} + \underset{\text{(oxygen)}}{6O_2}$$

$$\underset{\text{(sugar)}}{C_6H_{12}O_6} + \underset{\text{(oxygen)}}{6O_2} = \underset{\text{(carbon dioxide)}}{6CO_2} + \underset{\text{(water)}}{6H_2O}$$

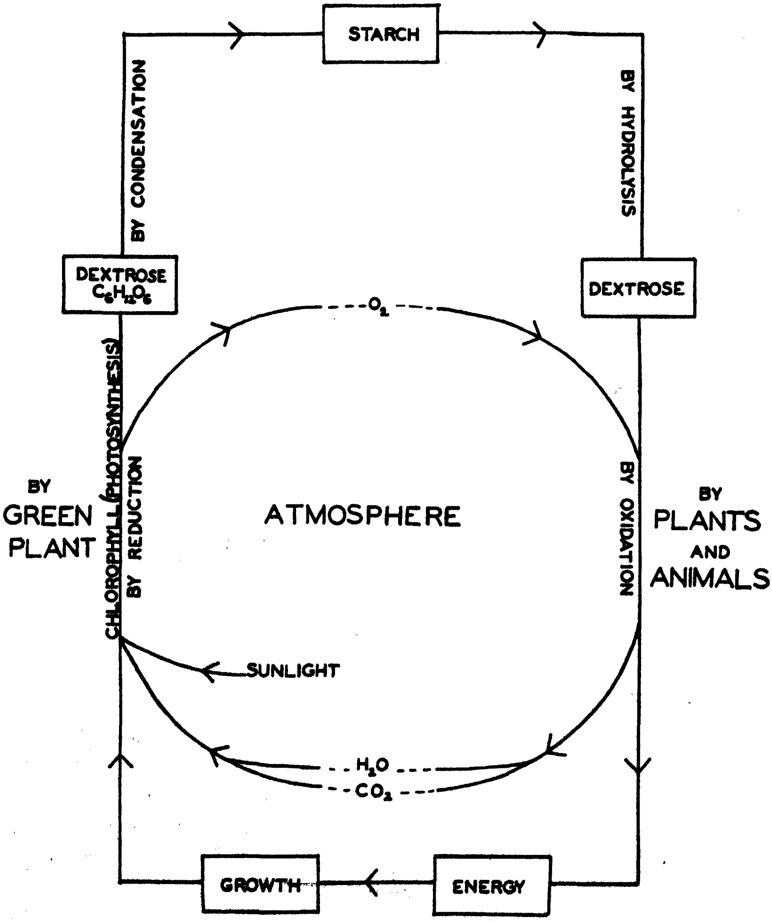


Fig. 98.—The carbon cycle.

THE NITROGEN CYCLE

Nitrogen is the element common to all proteins through the NH_2 group. Sulphur is found in only two of the amino acids and phosphorus in none, although phosphorus may be added to the protein molecule when condensation of amino acids occurs. The steps of the nitrogen cycle may be stated briefly as follows.

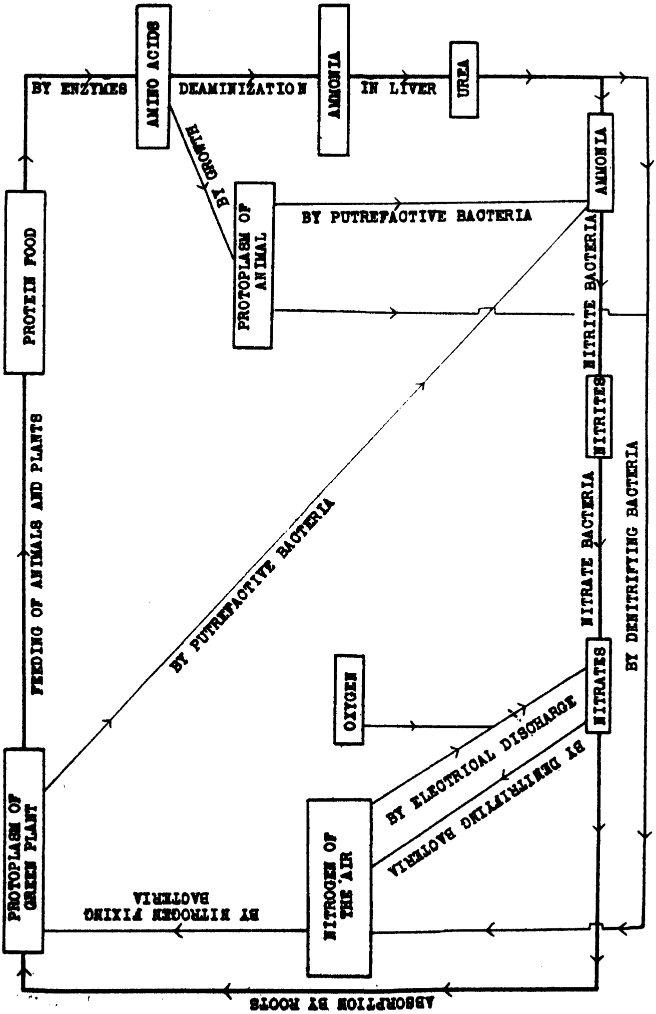


Fig. 99.—The nitrogen cycle.

1. Plant tissues eaten by the animal as protein food.
2. Proteins digested by hydrolysis to amino acids.
3. Proteins built by condensation of amino acids in animal protoplasm.
4. Katabolic waste yields urea. Urea is also formed by deamination of amino acids in the liver.
5. Urea is excreted or animal dies.
6. Ammonia is released by bacterial action on urea or on dead tissues.
7. Ammonia is oxidized to nitrous acid by nitrite bacteria, *Nitrosomas.*

$$2\,NH_3 + 3\,O_2 \rightarrow 2\,HNO_2 + 2\,H_2O$$

8. Nitrous acid combines with bases to form nitrites.

$$HNO_2 + NaOH \rightarrow NaNO_2 + H_2O$$

9. Nitrites are oxidized to nitric acid by nitrate bacteria, *Nitrobacter.*

$$2\,HNO_2 + O_2 \rightarrow 2\,HNO_3$$

10. Nitric acid combines with bases to form nitrates.

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$$

11. Nitrates absorbed through root hairs of green plants.
12. Synthesis of amino acids in plant cells.
13. Condensation of proteins from amino acids in plant protoplasm.
14. Plant tissues eaten by animal as protein food.

THE SULPHUR CYCLE

The sulphur cycle is similar to the nitrogen cycle. Hydrogen sulphide is formed during the decomposition of protoplasm. This is oxidized by sulphur bacteria into sulphurous acid which combines with bases in the soil to form sulphites.

The sulphites are further oxidized by bacterial action to form sulphuric acid which combines with bases to form sulphates.

Some sulphates are excreted by the animals in a form which can be utilized by the plants direct, in which case no bacterial action is essential to the completion of the cycle.

THE PHOSPHORUS CYCLE

The decomposition products of phosphorus compounds usually contain phosphoric acid which will combine with bases to form phosphates. In some cases, however, bacterial action is believed to intervene in the completion of the phosphorus cycle.

Soil Fertility

In the natural course of events all these elements would be kept in circulation by the activities of animal and plant metabolism, but the long-continued cultivation of crops for commercial use often drains the soil of its mineral supply.

It has become necessary, therefore, to fertilize the soil by artificial means where land is used continuously for cultivation. Animal excrements have long been used for the purpose and are the logical source, since these furnish the necessary materials for completion of the cycles. The excreta of those birds, known as the guano birds, which abound off the coast of Peru, have been utilized to such an extent that government intervention has been necessary to prevent their extinction. These birds, of which the penguins are a familiar example, build nests of their excretions which are piled up year after year until whole islands are covered with masses of excreta. This is called guano. Its commercial value is great, but the sources are limited, and more and more farmers are coming to depend upon other sources of fertilizer.

There are rock deposits which are rich in phosphates, and others which yield nitrogen compounds, especially the potassium and sodium nitrates. Chile saltpeter is a sodium nitrate which has been widely used. Potassium compounds can be obtained from seaweeds.

Alternation of crop plants with leguminous plants, thus utilizing the nitrogen fixing bacteria which live in the root nodules is a method widely used by farmers for maintaining the nitrogen supply, though the electrification of atmospheric nitrogen bids fair to outstrip all other sources for nitrogen fertilizers.

Associations

As a result of the cycles established in nature, plants and animals all tend to live in more or less close association with other plants and animals. Green plants can populate new regions independently, but animals, seeking plants for food, will quickly follow them, and communities will be built up in which each species has access to the necessities for self-preservation. The relations established will involve a constant competition; the plants, competing for light and moisture; the animals, for food. Any species will be prevented from overproduction by the rigors of this competition.

External Factors.—As with the individual animal or plant, the relations of the community will involve an interaction between the internal and external environment. The factors of the external environment determine the geographical distribution of animals and plants by longitude, latitude, and altitude. These factors may be either chemical or physical.

Chemical Factors.—The chemical factors include the salinity of the water and the acidity of soil. Salinity varies in lakes, rivers, and oceans, and determines the osmotic pressure of organisms living in the water. The roots of plants are affected by acidity. The conditions are usually local.

Physical Factors.—Conditions of temperature, moisture, light, and barometric pressure are physical factors. They are subject to seasonal variations, and to day and night contrasts, and are, therefore, the factors of climate.

The intensity of the light rays depends upon the angle at which they strike the earth, and temperature, length of day and night, and seasons are determined thereby. The amount of moisture and the frequency of rainfall are expressed in the aridity or humidity of a region, and have a definite effect on transpiration. Barometric pressure varies with altitude and increases with depth. Thus pressure is greatest in the depths of the sea, and least on the mountain tops. Only animals can live in the sea depths beyond the point penetrated by light rays. All other depths and heights are populated by both plants and animals.

The distribution of animals and plants is determined by these factors more than by any other, since only those adapted to the specific conditions of a region will survive there. Thus similar climatic conditions will develop similar communities the world over.

Internal Factors.—The internal factors of the community are determined by the relation between the animals and plants in the community and are known as the *biotic factors.* These relations may be so close that the organisms live permanently together. They may be mutually helpful, as in *symbiosis,* or to the benefit of only one. Parasites derive nourishment from living hosts, saprophytes from dead ones. Epiphytes depend on other organisms for support, but derive no food or water from them. These are found only in plants.

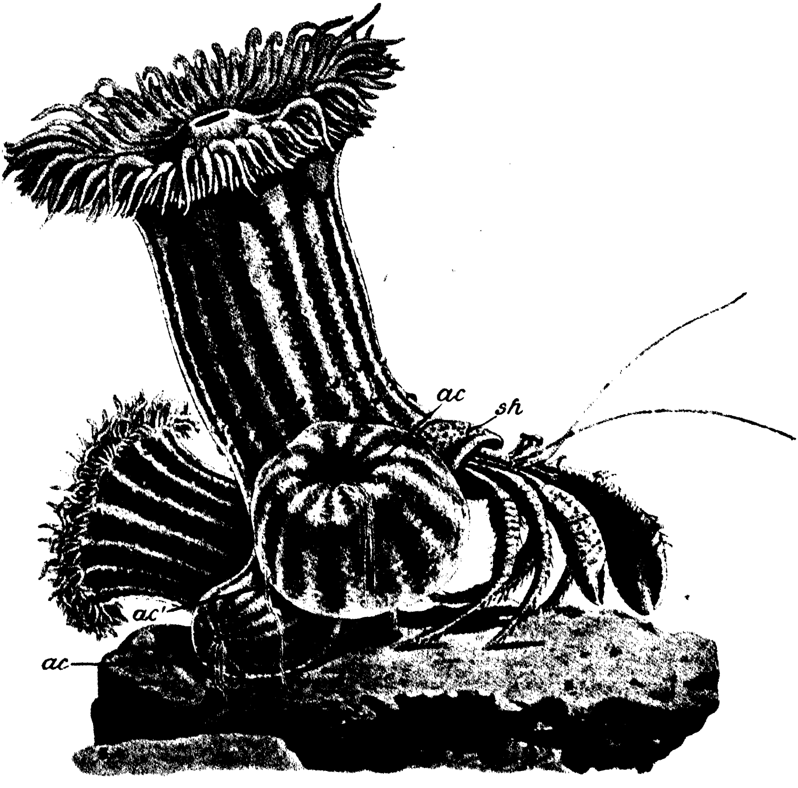


Fig. 100.—Hermit crab carrying four sea anemones attached to its borrowed shell, *ac,* acontia; *sh,* shell of crab. (After Andres.) (Reprinted by permission from Parker and Haswell: Zoology. Published by The Macmillan Co.)

Symbiosis.—In the small fresh-water animal, *Hydra viridis,* the green color is due to symbiotic Algae which live in the cells of the Hydra. The Algae use the carbon dioxide of the animal, and the Hydra, in turn, uses the oxygen liberated by the plants.

Lichens are composed of colorless plants of the cup fungus variety which live in close union with certain green algae. It is not an absolute union, however, since the algae can exist without the fungus, while the fungus cannot live alone. The benefit of this life, however, is mutual, the fungus supplying the necessary moisture and protection, while the algae make the food.

The relation between the plant lice and the ant colonies is a symbiotic relation. The ants capture the lice at the end of a summer season, carry them to the ant colony, and live on the "honey dew" secretion of the "cows," which they milk daily. In the spring, they carry them back to the host plant.

Commensals are animals which, like epiphytes among the plants, derive benefit by living with a host, but not from the host itself. The hermit crab, which occupies the shell of a snail, carries a sea anemone attached to the borrowed shell. The sea anemone secretes a disagreeable fluid which is distasteful to the fish which usually feed upon the hermit crab, and its presence is a protective measure. In turn, the hermit crab carries the sessile animal from place to place, thus increasing its chances of a wide variety of food.

Other associations are less close but none the less dependent. E. J. Allen has worked out the relations between the mackerel in the sea and the copepod plankton on which they feed, showing that the catch of mackerel in any given region will be due to the amount of sunlight available during that season.

Plankton is a floating community on the surface of the ocean, held together by a tangle of seaweeds. Many minute animals and plants live in the mass, the dominant animal forms being the minute arthropods called copepods. These live on the unicellular algae and diatoms which, in turn, depend upon the sunlight.

Sometimes members of a species tend to stay together, as in schools of fishes, herds of mammals, and flocks of birds. Ant and bee colonies are a high order of such intraspecific relations, with division of labor between individuals.

COMMUNITIES

More often the interrelationship is without close contact but essential, nevertheless. Communities grow by definite stages and may reach a state of equilibrium, in which the balance of births and deaths is stable. Such a balance may be upset by environmental change, whether natural, by floods, or artificial, by fires; or it may be upset by the introduction of some new species foreign to the community.

Development of a Community

Communities are initiated by the plants which show a fairly definite progression in the population of new areas. The first colonization of bare areas is by mosses, algae, or lichens. Whether the area is dry, damp, or quite wet, it can be colonized, for in time, the dry area will become damp from the humus which accumulates, and the wet area will become filled in by humus and made of a similar dampness. Thus the second stage may be similar in both cases.

Winds scatter seeds from fairly distant places, and these falling on the humus may germinate. Of the few seedlings which start growth, only those which require no shade will have any success. A few hardy herbs may survive, however, and their shade will furnish the necessary protection for more delicate ones. It will have the added function of drying out the soil and killing the carpet plants which had preceded them. Shrubs are the next invasion and these are succeeded by small trees. Eventually, a *climax* community is built up in which the tree is the dominant feature and in which successive associations have been driven out until an equilibrium has been reached.

Throughout its growth, animal associations will have been established, at first transitory and shifting, but finally of a somewhat permanent character. The first animal invaders will be the insects. Aided by the wind and guided by tropisms, they may be searching for specific plants, or they may make a haphazard selection. In the latter case, their stay will be limited. Birds are early visitants, some looking for seeds, others for insects; they may establish a more or less permanent association. Later terrestrial forms, salamanders, snakes, and small mammals will make their appearance, and lastly the large mammals, arriving only when the small groups have established a fairly adequate food supply.

A Climax Community

A climax community is one which has ceased to change in composition, at least with regard to the dominant species. It has established a complete equilibrium between its internal and external factors. Such communities are common in the Pennsylvania forests where the tree is the dominant organism. In the coniferous forests of Pennsylvania the hemlock, beech and yellow birch association shown in Fig. 101 is a typical climax community. In the deciduous forests the beech-maple association is the final stage.

In the forest community the tall trees have the first access to the sun's rays. Light and rain filter through the foliage and are tempered in intensity before reaching the forest floor. The shade they produce reduces the amount of evaporation from the surface, and the air is damper in the forest than outside. Leaves falling from the trees form a layer of humus over the soil, giving a rich surface layer, and yet only those herbs which flourish in relative darkness can thrive there.

Ferns rise to a higher stratum than herbs but are still shaded. Shrubs and low trees benefit by successively more and more light as their foliage occupies a higher stratum and nears the dominant foliage. Epiphytes may grow among the high branches and thus gain a maximum of light while gaining support from the trees. Mosses and lichens may live on the barks of the trees. The undergrowth in Fig. 101 consists of hobblebush *(Viburnum alnifolium)* and ferns *(Dryopteris spinulosa* var. *intermedia)*.

The strata established by the vegetation are occupied by animal life also. The subsoil is inhabited by worms which emerge at night to eat the fallen leaves. Moles, snakes, and groundhogs also burrow for shelter underground.

The surface life is the most varied and the most active. White-tailed deer, opossums, foxes, skunks, weasels, groundhogs, rabbits, mice, grouse, pheasants, quail, snakes, toads, insects and spiders all make their homes in the Pennsylvania forests.

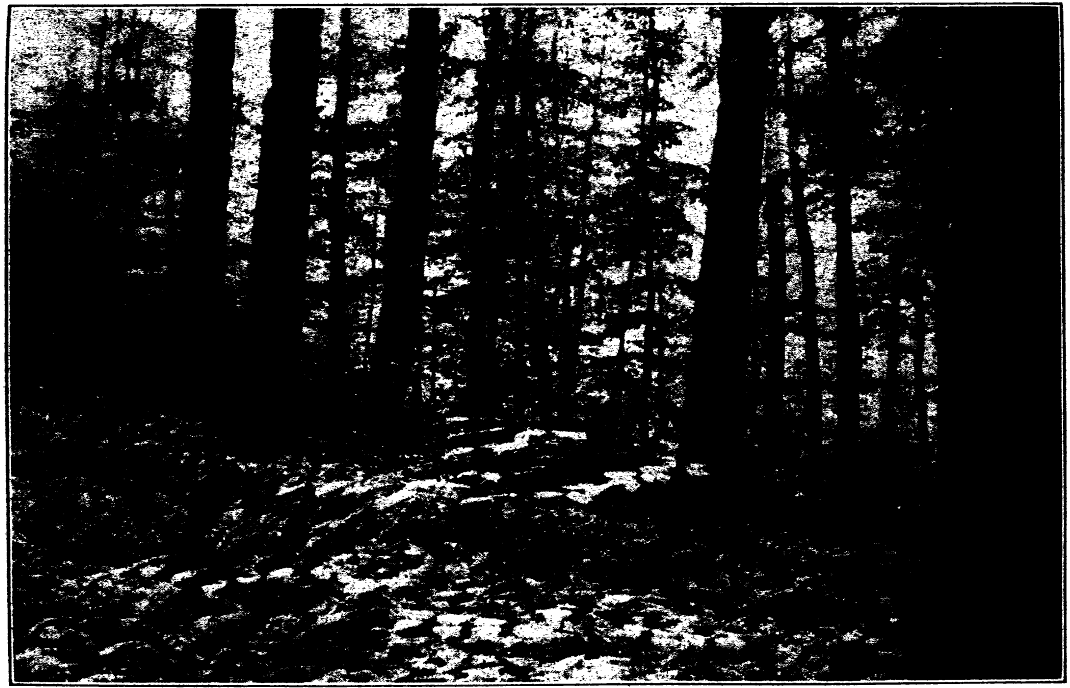


Fig. 101.—Climax forest in McKean County, Pennsylvania. Dominant trees hemlock *(Tsuga canadensis)* associated with beech *(Fagus grandifolia)* and yellow birch *(Betula lutea)*. Hobble bush *(Viburnum alnifolium)* and ferns *(Dryopteris spinulosa* var. *intermedia)* form the lower strata. (Photograph by Robert Benson Gordon.)

The tree trunks make homes and feeding grounds for nuthatches, woodpeckers, owls, creepers, tree frogs, spiders, and insects.

The low branches and shrubs house the warblers and many insects.

The higher branches are inhabited by tanagers, pewees, chickadees, and insects.

The treetops house the hawks and crows.

In an established equilibrium each species is assured of an adequate food supply. In acquiring the food, however, each species may provide food for some other species, so that every animal in the forest has a food supply and one or more enemies. In this way, overproduction is avoided. Each food chain leads eventually to plant food, since all animals, if they feed on other animals, derive material from the plants which other animals have eaten. A few food chains from the forest animals will illustrate this. The white-tailed deer feed upon vegetation directly, eating tree mosses, buds, and leaves of shrubs and low trees. Their danger lies in eating certain plants, like laurel, which poison and kill them. Foxes feed on small mammals and game birds, as well as on mice and rabbits. The game birds, mice, and rabbits feed on vegetation. The small mammals, such as weasels, feed on squirrels, rabbits, game birds, groundhogs and mice, all of which feed on vegetation. Birds, too, establish food chains. The hawks feed on small birds, garter snakes, rattlesnakes, and some small mammals and mice. The birds and snakes feed largely on insects which, in turn, live on vegetation. The rattlesnake may feed on mice, and the small mammals on squirrels, rabbits, etc., which, in turn, feed on the vegetation.

Certain food chains operate only at night, so that animals which might be natural enemies may never meet. Thus the owl emerging in the evening will never meet the warblers which feed by day. Owls feed on large moths, which fly at night, and on mice. These, in turn, live on vegetation. They may also attack moles which live on insects which, in turn, live on the vegetation.

There is also a seasonal variation in the food chains. These are intimately concerned with the breeding habits and are well timed with the available food supply. They are best illustrated by the birds which migrate south in the fall and return in the spring in time for the returning activities of the forest. In February the winter birds take up a suspended activity. These are largely birds of the blackbird family and are grain eaters. In March the seed eaters, sparrows, finches, etc., begin to arrive just as the blossoms begin to appear on the trees. The arrival of the flycatchers in April is timed with the first hatchings of winged insects, and later, in April and early in May, the warblers appear in time for the rich crop of summer larvae.

Animals tend to eat species which are smaller than themselves, and, since it takes more of the small species to satisfy the hunger of a larger one, there is a pyramid of numbers established by the food chains and related to the breeding habits. One hawk usually dominates a large area of forest, and the deer and foxes are scarce. Small mammals and small birds occur in relatively larger numbers, but mice, toads, and salamanders outnumber them. The species which abound, however, are the insects which provide food for the largest number of species.

PART II

PROBLEMS OF BIOLOGY

CHAPTER XI

SOME PROBLEMS OF BIOPHYSICS AND BIOCHEMISTRY

Any study of protoplasm must take into consideration the work of the physicist and chemist since protoplasm is matter in a state of viscosity, and the state in which any matter is found depends on the space between the molecules that compose it. A piece of lead is more solid than protoplasm. On the other hand, water is more liquid, and oxygen is a gas and cannot be held in an open container.

Some of the largest molecules have been brought within the range of vision by means of the electron microscope, but the size of atoms still remains a matter of mathematical calculation. Each molecule is made up of two or more atoms. An element is a substance, all of the atoms of which are alike. There are ninety-six known elements at the present time. Some are solids (carbon, iron, copper, lead) one at least is a liquid (mercury), and many are gases (hydrogen, nitrogen, oxygen).

If one started with the cube of any element with each face one foot square and continued subdividing, eventually it would subdivide into the ultimate atom. If the cube were of lead, the atom would be reached at the twenty-eighth subdivision as the following calculation by Jacobs shows.

The 9th subdivision reaches the limit of balance
The 10th subdivision reaches the limit of visibility
The 14th subdivision reaches the limit of microbalance
The 15th subdivision reaches the limit of spectrum analysis
The 16th subdivision reaches the limit of microscope
The 17th subdivision reaches the limit of ultramicroscope
The 28th subdivision reaches the limit of ultimate atom of lead

Another way of arriving at some idea of size is to think of a single Paramecium which is a minute mass of protoplasm and imagine it blown into its ultimate atoms so that they are uniformly distributed over the face of the earth. If each atom had been made radioactive so that its position could be traced, one thousand atoms of the original Paramecium would be found in each square foot of the earth's surface.

Rutherford has conceived of the atom as a minute solar system in which *electrons* with negative electrical charges revolve around a nucleus containing *protons* with positive electrical charges, and often *neutrons* with negative charges. To revolve around anything requires space in which to move, and the space must be larger than the substance moving in it. What appears to be a solid piece of matter, therefore, is in reality, a meshwork of spaces within which the perpetual activity outrivals man's passion for speed.

The nucleus determines the mass of the atom, and the number of protons in it determines the atomic number of the element. Thus hydrogen has 1, carbon 6, nitrogen 7, and oxygen 8. In addition, the nuclei of carbon, nitrogen, and oxygen contain as many neutrons as protons, and the atomic weight is thus double the atomic number. Hydrogen can be made to exist with a closer union between its proton and electron, in which case it behaves as a neutron. All radioactivity in the atom originates in the nucleus, and by the shooting out of neutrons, radioactive elements lose weight.

Hydrogen with but one proton and one electron is the unit of the elements, all other elements being aggregates of hydrogen. As the protons increase in the nuclei, the electrons increase also and frequently occur in two or more shells. To picture the plane of one of these shells one may think of a cube with an electron at each of its eight corners. All eight would be in one shell but not all in one plane. Since the protons have a positive charge they attract the electrons, but the neucleus is not in the exact center so that their paths are somewhat elliptical, and since electrons repel each other, the path is never smooth and continuous.

All chemical activity in the atom takes place in the outer shell and depends upon the number of electrons there. When there are eight, the shell is complete and the substance will be inert. At one end of each series of the periodic system of elements is an inert gas having eight electrons in the outer shell.

When there are less then eight, electrons may move from one shell to another. If they move from the outer shell to the inner shell, a measurable amount of light is emitted. When the movement is outward, light will be stored in the nucleus. Thus the nucleus contains all of the energy of the atom. Only nuclei of high atomic weight are sufficiently unstable to initiate radiations in the natural state, and radioactivity is one form of destruction for which there is no corresponding constructive process.

About forty radioactive elements are known; radium 230, thorium 232, and uranium 238 are the commonest. Probably elements of higher weight than uranium do not exist, for they would be too unstable.

Three types of radiation are emitted: the alpha, beta, and gamma rays. Alpha rays are helium nuclei and are the swiftest of all radiations. Beta rays are streams of electrons of varying frequencies, and gamma rays are electromagnetic waves of varying lengths merging into the ultraviolet rays. Gamma rays are the most penetrating since they are not deflected by electric fields, and it takes atoms of considerable size to stop them. Since the weight of hydrogen is 1, of carbon 12, of nitrogen 14, of oxygen 16, of calcium 20, and of lead 82, it is easy to see why lead can be used effectively as a shield against these radiations, and why bone with a large amount of calcium leaves a shadow on the x-ray plate.

As neutrons shoot out of the nuclei, the elements lose weight and eventually change into different elements. Thus uranium becomes plutonium, and radium, radon. These are still radioactive but less so than in the original state. In time, all radioactive elements will become inert. The inert stage is lead, and the amount of lead in the rocks today is an indication of past radioactivity.

If the neutrons shot from an unstable nucleus enter another element, that element will increase in weight and become radioactive. Such elements are *isotopes* of the element activated; that is, they have the same chemical qualities but differ in weight. Isotopes of the elements have been known since 1906, but only recently have they been made artificially by atom bombardment. Elements that have been subjected to bombardment are called *radioisotopes.* When these are made to enter the tissues of animals and plants, they can be followed by sensitive instruments, and so are called *tracer elements.* They are the most recently acquired tool in scientific research, and much is expected of them.

There are two main methods of obtaining isotopes:

1. The cyclotron and betatron produce a variety of radioisotopes by utilizing different atom-bombing projectiles at different energies. The limit of the cyclotron in 1945 was 100,000,000 volts of electricity. Already proposals have been made for a synchrotron to produce 1,000,000,000 volts.

2. The chain-reacting uranium piles set up during World War II produce radioisotopes by slow neutron bombardment. A veritable hurricane of neutrons is constantly raging inside the piles which are kept behind thick concrete walls. This type of bombardment produces isotopes by only two processes; by fission and by gamma ray radiation. There is less variety to the isotopes made radioactive by this method, but the yield is much greater.

The uranium pile at Oak Ridge, Tennessee, is now producing radioisotopes for research. Four other piles are expected to be put into operation soon. Over 400 radioisotopes of the ninety-six elements are known, and 100 of them are available for research. The distribution is under control of an advisory committee nominated by the National Academy of Sciences. The isotopes retaining their radioactive qualities for more than twelve hours are kept in stockpiles for distribution. Those whose activity decreases more rapidly are made to order.

Some of the radioisotopes now in use are carbon 14, oxygen 18, sulphur 35, phosphorus 32 and iodine 131. The normal weight of these elements is carbon 12, oxygen 16, sulphur 32, phosphorus 31, and iodine 127. Since these elements are all found in human tissues, much information is expected of them regarding both normal and abnormal growths. Photosynthesis is already under investigation (see page 115), and the medical profession is looking to radioisotopes for a method of cancer control. Certain radioactive elements find their way directly to abnormally growing tissues.

Molecular Movement

Considering the activity within the atom, it is not difficult to conceive of the molecule in motion as well. The space which any molecule of gas can traverse in space without meeting another molecule determines the viscosity of the gas. No gas can be cooled indefinitely without becoming a liquid, and no liquid can be cooled indefinitely without becoming a solid. Cooling lessens molecular motion by bringing the molecules closer together; hence, the less the movement of the molecules, the firmer the substance. In a liquid the molecules are less confined than in a solid, but the majority of them cannot escape into the air, while in a gas there are no limits to the movement of the molecules except within the walls of a closed container. They will quickly fill such a container until the density of the gas is uniform throughout. Volatile liquids like ether escape into the atmosphere when the container is open but not as rapidly as a gas, and water evaporates slowly.

When molecules of two kinds are present in a solution, the more dense substance will diffuse slowly through the solution until all molecules of both solutions are equal distances apart. They will be impeded in their progress by the collision of molecules so the process will be slow.

Electrolytic Dissociation

Not all substances in solution retain their molecular structure. Some, like sodium chloride, instead of separating into molecules of NaCl, separate the sodium ion (Na^+) from the chlorine ion (Cl^-). The sodium ion bears a positive charge, and the chlorine ion, a negative charge. When a current of electricity is passed through the solution, the sodium ions pass to the negative pole and the chlorine ions to the positive pole, thus losing their electrical charge.

Such substances are known as *electrolytes*. They include acids, bases, and salts. *Nonelectrolytes* which will not conduct an electrical charge are sugars and alcohols. Protoplasm is an electrolyte (or mixture of electrolytes) because the proteins in its composition possess *amphoteric* properties which enable them to act under some conditions as acids and under others as bases.

Acid-Base Equilibrium

Hydrochloric acid is dissociated into the positive hydrogen ion (H^+) and the negative chlorine ion (Cl^-). Sodium hydroxide is dissociated into the positive sodium ion (Na^+) and the negative hydroxyl ion (OH^-). The hydrogen ion is what gives to any acid its acidity, and the hydroxyl ion is what gives to any base its alkaline qualities. Therefore the number of hydrogen ions in any solution will be an index to its acidity. This is known as the *hydrogen ion concentration,* frequently referred to as pH.

The hydrogen ion has toxic qualities and sometimes acts as a catalyzer hastening hydrolysis in digestion. Of the greatest importance in vertebrates is the H ion content of the blood. Normally, blood is faintly alkaline in reaction. During respiration carbon dioxide is being given off from the tissues to the blood and the H ion concentration of the blood would be expected to show a rise, but the rise is very slight. When the acid by-products of muscle metabolism enter the blood stream, as lactic acid, no appreciable rise in acidity occurs. This is due to the presence of so-called *buffers* in the blood.

If the basic phosphate K_2HPO_4 and the acid phosphate KH_2PO_4 are present in any solution in the proportions to give a neutral reaction, the addition of further H^+ or OH^- ions will not further increase the acidity or alkalinity of the solution. If the H^+ ions are added, there will be a shift of HPO_4 to H_2PO_4 and the H^+ ions will have disappeared. If the OH^- negative ions are added, the shift will be the other way from H_2PO_4 to HPO_4 and the OH^- ions will have disappeared. In a range between pH 5.8 on the acid side and 8 on the alkaline side, this mixture shows a remarkable power to absorb a large proportion of the H^+ or OH^- ions added to them. Thus they are called *buffers* since they absorb the shock of excess ions. Carbonates and bicarbonates form a similar combination, and the presence in the blood of both combinations helps to maintain the normal acid-base equilibrium. In severe metabolic diseases, such as diabetes or nephritis, the acidity may pass the range of buffer control and acidosis result.

Surface Tension

The molecules on the surface of any liquid are under more tension, or pull, than those underneath. This gives to the surface certain properties not possessed by the bulk of the liquid. Thus a needle can be made to float upon the surface of water, provided it does not pierce the surface; and the hardness of the surface as compared to the water underneath has been felt by inexperienced divers.

It is the tendency of the surface to occupy the least amount of space. Thus, where the surface of one liquid is immersed in another, pressure will be equal on all sides, and the immersed liquid will assume a spherical shape. This is true of a soap bubble, which is a solution with two surfaces close together and therefore an excellent object upon which to study surfaces.

The globular shape of the soap bubble released from the pipe is the shape required by the law of minimal surfaces. Should another bubble be brought in contact with it, a flat surface would form between the two, and where four or more bubbles come in contact there will be seen the pattern which is encountered in animal and plant cells when they come in contact. The surface of a cell has a tension, and where it presses against the surface of another cell, a flat interface will form.

If a soap solution be allowed to form a film on a wire ring, and the wire be bent at right angles, the shape assumed by the film will demonstrate the pull which causes it to occupy the least amount of space.

There is no better demonstration of the phenomenon of surface tension than a dividing egg cell. This minute cell is plastic and, therefore, assumes a spherical shape. Whether surface tension phenomena are sufficient to explain cell division or not is uncertain, but anything which lowers the surface tension can be used to cause division in artificial parthenogenesis. If a drop of rapeseed oil be immersed in an alcohol-water mixture and supported from the bottom by running in some concentrated salt solution, and alkali be applied to two poles simultaneously, the surface tension will be reduced by soap formation at the poles, whereas the original surface tension at the equator will act as an elastic band and constrict the drop into two drops.

Just prior to cleavage the protoplasm of the egg becomes more liquid. After the cell divides, the interfaces are flatter between the two cells for several minutes, after which time they tend to round up slightly. This is probably due to the greater dilution of the protoplasm, allowing it to occupy a smaller space. When four and eight cells are formed, the interfaces exhibit the same configurations seen in the soap bubbles, showing that the shape of the dividing eggs is controlled by surface tension.

Pseudopodial formation in an amoeba is another example. If the tension be lowered at any point of the ectoplasm, a pseudopodium will be formed at that point. The tiny droplets which one sees on a spiderweb are rounded up by surface tension. The spider secretes these at the rate of fifty per second, and sometimes there are as many as twenty in one-tenth of an inch, each one a perfect little sphere. Just so, the dewdrops on the grass in the early morning are shaped by surface tension.

Adsorption

According to *Gibb's principle,* anything which when dissolved lowers the surface tension of the solvent, tends to collect at the free surface. This property is known as *adsorption.*

If animal charcoal be shaken up with a solution of gentian violet and then filtered, the charcoal on the filter paper will have the dye adsorbed on the surface. This is a purely physical phenomenon, no chemical combination taking place. The charcoal can be washed with water any number of times and only traces of the dye will come off. If, however, alcohol be poured over the charcoal, the charcoal will release the dye, the filtrate coming through a deep purple.

The leucocytes, the white blood corpuscles, which are known as the scavengers of the blood stream, have the property of phagocytosis. They will take up carbon in the lungs and later some are swept up the windpipe by the action of the cilia lining the trachea. Others find their way to the lymph glands in the vicinity of the lungs and heart, a region known as the *mediastinum,* and may color them black. Thus carbon may be removed without injury to the lungs. Workers who breathe coal dust are farr less likely to contract tuberculosis than are those who breathe silicious dust in factories and quarries. It has not been shown that phagocytosis is entirely a process of adsorption or that the differential adsorption of silica and carbon explains all the diferences between the reactions to the two kinds of dust. In part, however, adsorption is involved. Enzymes, too, may owe their capacity to depart from a reaction unchanged to the power of adsorption.

Permeability of Membranes

The force exerted by either molecules or ions in solution against the living membrane is measurable and is proportional to the concentration of the solute. Living cells are bathed in salt solutions, and the pressure against the walls tends to keep them in a state of turgor. When the pressure is equal on both sides of the membrane, the solution outside is said to be *isotonic* with the solution inside the cell.

In mammalian tissues the pressure exerted is about 7.1 atmospheres, which is equal to the pressure of 1 gram of sodium chloride (NaCl) in 100 grams of water. Such a solution, therefore, is isotonic for mammalian cells and can be used with safety when working on their living tissues. It may also suffice for the toad, but the frog in water is isotonic with about 0.75 per cent NaCl solution.

The osmotic pressure in plants is much higher. The pressure of the cells of an apple has been calculated to be as high as 17 atmospheres. This pressure is shown in the plant by the turgor which holds the plant erect. The pressure from within causes the plasma membrane to swell, thus exerting pressure on the cell walls.

When pressure is unequal on two sides of a membrane, water will pass unequally in two directions, and damage to the cell will result. If there is less water outside the cell than inside, the solution is *hypertonic.* Water will pass out of the cell until the pressure is equalized. In a plant cell under these circumstances, the protoplasm may be seen to shrink away from the cellulose wall which is too resistant to yield to the pressure. This is called *plasmolysis.* If blood corpuscles are placed in hypertonic solutions, they will shrink, since the cell membrane is too delicate to resist excessive pressure. Such corpuscles are said to be *crenated.*

Conversely, a *hypotonic* solution will be less dense than the protoplasm and the pressure will be greater outward. Water will enter the cell. In a plant cell this will distend the wall by pressing against the cellulose; in a blood corpuscle the delicate membrane will break under pressure and the cell will burst. If corpuscles break, the hemoglobin goes into solution in the plasma. Such blood is said to be *hemolyzed.*

The Plasma Membrane

One of the earliest demonstrations by the microdissection method was the actual existence of the plasma membrane. Chambers found that only a sharp puncture with microscopically fine needles and pipettes would pierce the membrane of an Amoeba or an egg without injuring the cell. He found the membrane to be protective. Substances which do not normally diffuse through membranes, like eosin, will diffuse easily through the cytoplasm if injected through the membrane with a micropipette.

Overton conceives the cell surface to be composed of fatlike bodies, which some believe to be phosphatides and sterols. When these are combined in artificial membranes and are supported by a network, they can be made to demonstrate the osmotic properties of cell membranes. Colloidal membranes with very fine pores have been made to demonstrate similar properties, so the possibility exists that not all cell membranes are alike.

Electrolytes are ionized in the cell cytoplasm and have a high conductivity. The plasma membrane, however, has high electric resistance and acts as an insulator. In experiments on certain bony fish eggs the unfertilized eggs have been found to be impermeable to both water and electrolytes. If the eggs are treated with unbalanced salt solutions, the membranes become permeable to both water and electrolytes.

The unit of the plasma membrane may be looked on as a sandwich with a middle layer more permeable than the rest.

When lying flat it is impermeable, but if tilted it becomes permeable through the middle layer. This change may be the basis of irritability in cells. Many cells that show irritability have different osmotic properties when stimulated than when at rest.

The conductivity of the sea urchin egg to low frequency electric currents increases with stimulation to development, and it makes no difference whether the stimulation is due to normal fertilization or to the induction of artificial parthenogenesis. The unfertilized frog egg is impermeable to electrolytes, but on passing an electric stimulus from platinum or carbon electrodes through the distilled water in which it lies, electrolytes start to diffuse out of the egg and development begins. Piercing the egg of the frog with a needle has the same result. Changes in the permeability of the egg during normal development parallel the changes in surface tension (see page 210).

Conservation of Water

Normally aquatic organisms are adapted to the pressure of the medium in which they live, their body fluids being isotonic with the medium outside. Such organisms cannot be transferred to a water of different density without serious danger, unless the transfer is made gradually enough to allow a readjustment in the tissues. Fishes are protected by the scales which are impervious to water, and many invertebrates have heavy exoskeletons. Thus some organisms may exist in either fresh or salt water, or may be transferred without harm. If the scales of a fish be scraped from even a small area, however, the transfer will have an immediate effect.

The pressure of the sea increases with the depth. Fishes which live normally three miles down or more invariably burst before they reach the surface unless dredges are used which can be closed before the ascent begins. The bursting is due to nitrogen and other gases which form bubbles in the tissue, since gas is more soluble in water at high pressure than at low pressure. Divers may experience the same effect in rising too quickly. The pain of the bubbles pressing on the tissues is known as the "bends."

In a similar way the eggs and larval forms must be adapted to the pressures in their environments. Marine organisms frequently drop their eggs directly into the sea. In the fresh water they would imbibe too much water so are often laid in gelatinous masses or encased in impervious outer layers. Many adults at home in fresh as in salt water may have to return to the sea every year to lay their eggs. Thus the fresh water eel, Anguilla, migrates thousands of miles into the Sargasso Sea to spawn. Life on land presents pressure problems, also, and land animals lay eggs encased in shells of chitin or calcium carbonate.

Marine invertebrates often have free larval forms such as the *trochophore* larva of the marine worms, the *bipinnari* larva of the starfish, and the *veliger* larva of the marine clams. As a rule the young fresh water animal remains inside the egg until after the larval stage has been passed, or, as in the case of the fresh water clam, Unio, until the larva becomes a parasite on some fresh water fish. The larval tadpoles of the amphibians have external gills to cope with the water.

All these adaptations have a direct bearing on the pressure relations between the internal and the external environment. Scientists are agreed that life began in the sea, and blood is believed to have originated by sea water being enclosed within the body. Since the magnesium ion moves more slowly than does the sodium or potassium ion, bloods have tended to contain relatively more potassium and less magnesium than the sea water. All body tissues are bathed by salt solutions, and vertebrate embryos developing within a shell or a uterus are provided with membranes which surround the embryo with salt solutions, thus providing a watery environment for their development and cushioning them against shock.

Adaptations to rid the organism of excess water are found in all excretory systems. The fresh water Protozoa have contractile vacuoles which continually remove water, together with the wastes of the cell, and so prevent the cell from being waterlogged. In the vertebrates the kidney has evolved to remove the excess. The glomerulus of the kidney has the power of filtering off large quantities of water, and there are fewer glomeruli in the kidneys of marine fishes than in fresh water species.

In aquatic organisms the major nitrogenous end product is ammonia, which requires a plentiful supply of water for its dilution and excretion. It is extremely toxic when concentrated.

In the amphibia and reptiles the principal end product is no longer ammonia but urea, which is nontoxic to the tissues. In the birds and mammals a further concentration into urine is made possible by a water-absorbing segment, the "loop of Henle." In birds the action of the loop is reinforced by a cloaca. The kidney must always allow enough water to pass to prevent its ducts being blocked by solid masses of excretory material, but by allowing the urine to pass into the rectum instead of discharging it to the outside, advantage is taken of the power of the rectum to absorb water, and a semisolid urine is formed. In many insects the rectum absorbs water from the secretions of the malpighian tubules and a pelletlike mass is excreted.

CHAPTER XII

SOME PROBLEMS OF METABOLISM

Metabolism is the sum total of the biochemical activities of the living organism, including both the chemical rearrangement of molecules and the storage and release of energy. The constructive phases are *anabolic*. They are also *endothermal* since they store energy in the *potential*, inactive, form. The destructive phases are *katabolic* and *exothermal* since they release energy in *kinetic*, active, form. To release the stored energy, kinetic energy from the outside is essential. The union of atmospheric oxygen with sugar molecules is called *oxidation*. It releases the stored energy in sugar into kinetic energy which can be expressed in living tissues as *heat, mechanical energy, chemical energy, electricity,* and, in a few forms, as *light*.

Chemistry of Metabolism

All processes of metabolism are *reversible*. For every *oxidation* process, therefore, there must be a *reduction*, and for every *hydrolysis*, a condensation. The reverse process of respiration, which is an oxidation, is found in the *photosynthetic* activities of the green plant. This cannot be accomplished by the animal organism, so the continued presence of green plants is essential to the continued existence of animals. The sugars made by the green plant provide the potential energy for all the metabolic activities of the plant and animal organisms. This is expressed in the Carbon Cycle (page 192).

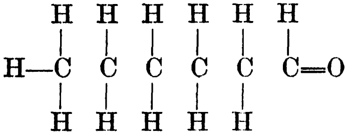
The chemical changes of metabolism are of three types: (1) the *hydrolysis-condensation* reactions, (2) the *oxidation-reduction* reactions, and (3) the *chemical substitutions*.

Hydrolysis and Condensation.—The process of digestion is a typical *hydrolysis*. In the digestion of starch $(C_6H_{10}O_5)_n$, one molecule of water (H_2O) is added to each starch molecule for every molecule of sugar $(C_6H_{12}O_6)$ removed from it. Conversely, when sugars are built up into starch, as when *glycogen* is formed from the digested sugars in the liver of the vertebrates, several molecules of sugar combine to make one large starch molecule. A molecule of water is removed from each molecule of sugar added. This is *condensation.*

The sugar molecules may be either *dextrose* (glucose) or *levulose* (fructose). The terms are interchangeable, dextrose and levulose referring to the power of these sugars to rotate polarized light to the right or to the left. Dextrose predominates in animal compounds; dextrose and levulose are about equally represented in plant starches. The levulose type is changed to dextrose in animals during the synthesis of animal starch, *glycogen,* in the liver.

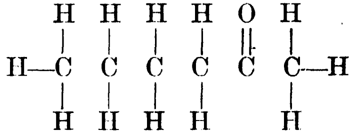
Both sugars have the same chemical formula ($C_6H_{12}O_6$), but the molecules are constructed on different patterns known chemically as *isotopes.* Dextrose is an *aldehyde* and rotates polarized light to the right. Levulose is a *ketone* and rotates polarized light to the left.

Dextrose



$$\begin{array}{cccccccc} & H & H & H & H & H & H & \\ & | & | & | & | & | & | & \\ H- & C & C & C & C & C & C & =O \\ & | & | & | & | & | & & \\ & H & H & H & H & H & & \end{array}$$

Levulose



$$\begin{array}{cccccccc} & H & H & H & H & O & H & \\ & | & | & | & | & \| & | & \\ H- & C & C & C & C & C & C & -H \\ & | & | & | & | & & | & \\ & H & H & H & H & & H & \end{array}$$

The reversible reactions may be indicated by two arrows ⇄. The letter (n) in chemical formulas stands for an undetermined number of molecules; thus, any number.

$$\underset{\text{starch}}{n(C_6H_{10}O_5)_n} + \underset{\text{water}}{n\ H_2O} \rightleftarrows \underset{\text{sugar}}{n\ C_6H_{12}O_6}$$

This formula, although chemically correct, does not represent the process as it occurs in the tissues, nor will the process occur without the activity of a *catalyst,* or *enzyme.* The process is rarely accomplished in one step, and the intermediate and by-products of metabolism are often very important. The enzyme *ptyalin* in the saliva, which initiates the digestion of starch, carries the process only halfway and the starch passes through the form of dextrin before becoming maltose. Maltose is a double sugar. Its further digestion is activated by the enzyme *maltase.* In a similar way the processes of condensation may involve intermediate steps.

Oxidation and Reduction.—The familiar conception of oxidation as the addition of oxygen to a molecule of sugar is questioned by the biochemists who look on all types of oxidation as changes in *valence* involving the movement of electrons. For students of biology, however, the physiologic conception is adequate since it focuses the attention on the oxygen and carbon dioxide exchange of respiration.

Oxidations may be of three types:

(a) Combining of oxygen with other elements with the consequent release of bound energy. The respiration of animals and plants is of this type. Free oxygen (O_2) combines with the sugar molecule ($C_6H_{12}O_6$). Carbon dioxide (CO_2) and water (H_2O) are formed, and the energy bound in the sugar molecule is liberated. Much of this energy takes the form of heat, but some is transferred into motion (animals only) and some into chemical energy for growth. In certain forms the energy of oxidation is expressed in electricity, and in others as light. The true respiration process in animals and plants takes place in the tissues. The surface exchange of oxygen and carbon dioxide is merely an osmotic exchange of gases. It is important as a means of measuring the internal respiration.

Photosynthesis is the corresponding reduction process. Oxygen is removed from the molecules and returned to the atmosphere. Just where in the process this occurs is an open question, since recent work with radioisotopes indicates that the radioactive oxygen introduced reappears in the water molecules excreted and not in the carbon dioxide, as expected. This is the only chemical process not common to plants and animals and the only process requiring energy from the sun. Light rays are absorbed by the chlorophyll, probably assisted by the enzymes in the chloroplasts, and their energy is transferred into the mesophyll cells to accomplish the synthesis of sugars. Some of the energy is bound into the sugar molecule where it remains in potential form until liberated by the next oxidation.

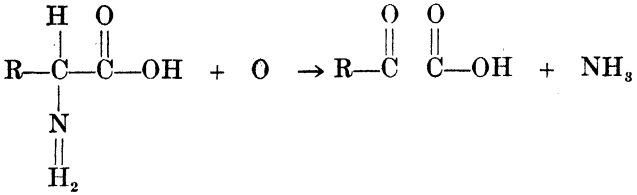
The reversible reaction is shown in the formula

$$C_6H_{12}O_6 + 6\ O_2 \rightleftarrows 6\ H_2O + 6\ CO_2$$

(b) Hydrogen may be removed from a compound and even though the hydrogen does not unite with oxygen but with some other element, it is conventionally called an oxidation.

The process is known as *dehydrogenation.* Its corresponding reduction process is *hydrogenation.* The deamination of proteins with the liberation of ammonia (NH_3) is sometimes accomplished by such an oxidation.

Oxidation

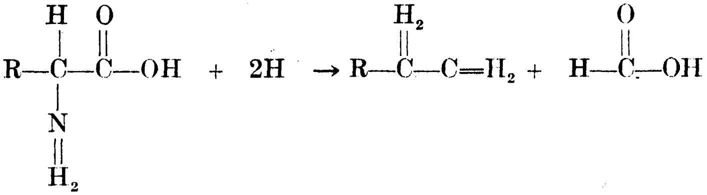


$$R\text{—}\underset{\substack{|\\ N\\ \|\\ H_2}}{\overset{\substack{H\\ |}}{C}}\text{—}\overset{\substack{O\\ \|}}{C}\text{—}OH + O \rightarrow R\text{—}\overset{\substack{O\\ \|}}{C}\ \ \overset{\substack{O\\ \|}}{C}\text{—}OH + NH_3$$

amino acid oxygen keto acid ammonia

In the corresponding reduction process, hydrogen is added to an amino acid to produce an amine and formic acid.

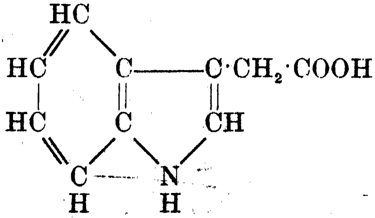
Reduction



$$R\text{—}\underset{\substack{|\\ N\\ \|\\ H_2}}{\overset{\substack{H\\ |}}{C}}\text{—}\overset{\substack{O\\ \|}}{C}\text{—}OH + 2H \rightarrow R\text{—}\overset{\substack{H_2\\ \|}}{C}\text{—}C{=}H_2 + H\text{—}\overset{\substack{O\\ \|}}{C}\text{—}OH$$

amino acid hydrogen amine formic acid

The R in the above formulas may be a simple CH_3 radicle or it may be a complex amino radicle such as is found in *tryptophane* which contains the ring structure. Deaminization of tryptophane by oxidation forms *indol acetic acid* which is better known as heteroauxin, a *growth hormone* of plants. The molecule of the hormone is shown here to illustrate the ring structure of the proteins. The ring depicted is known as the *indol ring.*



indol acetic acid

(c) Change in *valence.* According to the biochemists, every oxidation raises the *valence* of something. This means an increase of *electrical charge* and implies a corresponding decrease in the charge of something else. The electrical charge of a molecule is its *electrical potential.*

When an atom loses one or more electrons to another atom, it has been oxidized. It thereby gains in positive charges, or valence. The atom to which the electron becomes attached gains in negative charges and has been reduced. The two processes in that case will occur simultaneously and is spoken of as *oxidation-reduction.* It is the type of oxidation found in iron and other metals.

$$Fe^{++} \underset{\text{reduction}}{\overset{\text{oxidation}}{\rightleftharpoons}} Fe^{+++} + e^{-}$$

Chemical Substitution.—Ions of the same charge may replace each other. Thus Na^{+} may replace K^{+}, OH^{-} may replace NH_2^{-}. These replacements may occur in all the tissues and account in part for the multiplicity of compounds formed.

Activators

The chemical activities of metabolism just outlined will not take place in a laboratory at the speed or the temperature encountered in body cells. With the intervention of a *catalyst,* however, the activities take place readily. A catalyst is something which promotes a chemical action. In the oxidation process of respiration, the catalyst is an *oxidase.* An enzyme is a catalyst which has the property of activating a chemical process without itself being changed or involved in the reaction.

Every step in *anabolism* and *katabolism* has a separate and distinct activator. Usually these are enzymes, but in some cases vitamins play a similar role. Many other chemical substances are known which have functions very like the enzyme, but not all remain unchanged. Hormones cause specific functions to take place, but they have to be continually replaced from the gland secreting them. All body catalysts are now classified as activators. All activators have certain characteristics in common.

1. They are catalytic in action.
2. Minute traces of them are sufficient to stimulate the processes involved.
3. They are so specific in action that absence or deficiency of any one of them may lead to disease or death.

Activators in general are protein molecules or have a protein base. Vitamins, however, have usually been extracted as salts of organic acids. Only genes are known to be self-propagating and to have the power to mutate. All others are synthesized in the tissues, with the exception of certain of the vitamins which must be supplied in the daily diet.

In the following outline all known activators are listed. Only a few of the most familiar will be discussed.

LOCAL ACTIVATORS

INTRACELLULAR

Genes or substances produced by genes, causing cells to differentiate in specific ways during development

Enzymes, catalysts which activate the chemical activities of metabolism

Exoenzymes, produced in glands and transferred to the organs which utilize them

Endoenzymes, which activate metabolic activities in the cells which produce them

Proenzymes, which activate enzymes

Coenzymes, substances whose presence is essential to the activity of the enzyme

Anti-enzymes, substances which inhibit the activity of enzymes

REGIONAL

Organizers

Substances which may be produced by genes

Substances which predetermine regional development in embryos: eye, limb, etc.

Substances which predetermine growth gradients in embryos: axial and limb gradients, etc.

DISTANCE ACTIVATORS

SPREAD BY DIFFUSION

Growth factors in unicellular organisms

Growth hormones in plants

Neurohormones in animals

Molting hormones in insects

SPREAD BY CIRCULATION

- *Hormones,* substances secreted by the endocrine glands affecting organs at a distance and forming a system of chemical co-ordination in the body
- *Vitamins*
    - Vitamins synthesized by the tissues from chemicals in the food
    - Vitamins not synthesized by the tissues and so essential elements of the daily diet

PARA-ACTIVATORS: By-products of metabolisms which may affect correlation or differentiation: carbon dioxide, histamine, etc.

Enzymes

Enzymes are produced in all cells. The basic molecule is a protein, but there is attached to it a nonprotein *colloidal carrier* which gives to the enzyme an extensive surface area on which the molecules of the substrate concentrate by a process of *adsorption.* This makes it possible for the substrate to slip off the surface at the completion of the process and to leave the enzyme unchanged. It has been suggested that the colloidal carrier may be a *coenzyme* and not a part of the enzyme itself. The carrier also is said to impart the specificity to the activity of the enzyme.

Proenzymes.—Enzymes are secreted in inactive form called *zymogens.* They may be brought into activity by coming into contact with a *proenzyme.* Thus pancreatic *trypsinogen* is inactive until it comes into contact with the intestinal juice which contains the proenzyme *enterokinase.* This converts the trypsinogen into the active *trypsin.* Pepsinogen in the gastric juice is activated into pepsin by the H ion of the hydrochloric acid in the gastric secretion.

Coenzymes.—Even after being activated, the presence of certain ions, or of certain chemical substances, may be necessary before the enzyme can become attached to the substrate. This substance is called a *coenzyme.* The H ion of the gastric juice may act as both a proenzyme and as a coenzyme. The OH ions are necessary to the activity of the salivary and pancreatic enzymes. Thiamine chloride of the B complex group of vitamins acts as a coenzyme with certain oxidases, thus aiding in the oxidation processes in the tissues.

Anti-Enzymes.—Enzyme inhibitors are found in such organisms as tapeworms which live in animal digestive tracts in the presence of powerful tryptic enzymes without being digested by them. That they inhibit but do not kill the enzyme has been shown by the use of an extract from the tapeworm. This slows but does not destroy the trypsin. Anti-enzymes are believed to exist in the cells of the intestine to prevent the digestion of the tissues by their own secretions.

Enzymes enable cells to carry out the chemical processes of metabolism at a more rapid speed and at lower temperatures than are required in the laboratory. All chemical processes are activated by them, and since these processes are reversible, it depends upon the concentration of the substrate whether the action activated is anabolic or katabolic.

The activities of enzymes are so specific that separate enzymes are required for each type of substrate. Thus an enzyme acting on a carbohydrate will not affect a protein or a fat, and the enzyme *ptyalin* of the salivary secretions can act only on starches, not on sugars. Ptyalin carries the digestion of starches only halfway, an additional enzyme, *maltase,* in the intestinal juice being required to complete the hydrolysis. When completed, all carbohydrates are split into the single sugar molecules of *dextrose* or *levulose.*

Protein digestion requires several steps also. The *pepsin* of the gastric juice splits proteins into peptones and proteoses. The *erepsin* in the intestinal juice splits these molecules into their constituent *amino acids. Trypsin* in the pancreatic juice is a stronger enzyme, for it may carry protein digestion through all the stages of hydrolysis to the *amino acids.*

Hormones

The word *hormone* is derived from the Greek word *hormao,* to excite. It was first used in connection with the secretions of the ductless endocrine glands of the vertebrates because of their power to excite to action organs at a distance from the source of secretion. The hormones from these glands are no different in type, however, from the growth hormones of plants and the neurohormones of animals. It now appears that a close connection exists betwen the chemical activities of hormones and the functions of the nervous system in animals.

The hormones of plants are called *auxins* (for details see page 106). They are concentrated in the growing tissues of plants and tend to move to positions relative to the direction of stimuli such as light and gravity, and so control the tropisms of plants. When the stimulus is light, the hormones concentrate on the side away from the light and the subsequent quickened growth of the cells on the darkened side brings the stem or leaf nearer to the source of light. Thus both growth and conduction are controlled by the hormone.

In the vertebrates a secretion from the anterior lobe of the pituitary gland is known to control the growth of the long bones. A secretion from the thyroid gland, by controlling the rate of oxidation in the body, also controls the rate of growth, and in the growing infant adequate thyroid secretions are essential to the normal development of the mind (for details, see page 543).

The endocrine secretions have been found to control many of the organic functions. They act as chemical messengers to the tissues, and the secretion from one gland may affect the time and extent of the secretion from another. Secretions from the anterior lobe of the pituitary are known to regulate the secretions of the thyroid, the parathyroid, the pancreas, the adrenal, and the gonads. Altogether their effect is regulatory and interlocking. They provide a chemical coordination of body functions paralleling that of the nervous system.

That there is a close connection between the chemical type of coordination and the nervous is shown by the similarity of some of the endocrine hormones to those secreted at the endings of the autonomic nerves. *Neurohormones* have been identified at the endings of all autonomic nerves and in the myoneural junctions of some of the somatic nerves. In the myoneural junctions and in the parasympathetic nerves the secretion has been found to be *acetocholine,* but at the endings of the sympathetic nerves the secretion is *adrenaline.* This is the same hormone found in the secretion from the adrenal medulla, and in the embryo the tissues of the adrenal medulla come from the same embryonic tissue as do the nerves of the sympathetic system.

Neurohormones carry the stimulus across from the endings of the afferent neuron to the dendrites of the efferent neuron. It is probable that similar hormones will be found to carry the stimulus across all synapses of the nervous system, both in the vertebrates and invertebrates. To date, the evidence from the invertebrates is incomplete. Glandlike secreting cells have been identified in the nervous systems of worms, molluscs, myriapods, and insects, indicating a close correlation between the chemical and the nervous functions so that further research may be hoped to further clarify the relationship.

Thus there is a general similarity between all hormone activities, even though a large variety of specific hormones have been identified. When isolated they have proved to be protein molecules which differ from enzymes in that they are used up in the reactions they activate and so must be continually renewed.

From the facts cited it becomes clear, in spite of the incomplete picture, that there has been a close connection between the hormones and the development of nerves and that chemical coordination preceded the development of neural coordination. It was doubtless the first type of coordination to develop in the organic world. Hormones probably account for both growth and conduction in the unicellular organisms. Chemical control has been retained in the plant world, but in the animals the nervous system has evolved to take over one part of the original function. Both types of coordination have had a common origin, therefore, and are closely interwoven in their activities.

Vitamins

Of the known activators, vitamins have the greatest popular appeal since the lettered vitamins, A, B, C, and D, have long been recognized as essentials of the diet and since the dietary deficiency diseases like scurvy, beriberi, and ricketts have been brought under control. At the present time, however, vitamin deficiency is connected with such common failings as nervous exhaustion, and whole populations may be suffering from a lack of the necessary chemicals in the diet.

Before man acquired a taste for purified foods like white flour and polished rice, and before cold storage and canning became common, the normal diet probably contained a full complement of vitamins, and only in abnormal circumstances such as prolonged sea voyages where fresh food was unobtainable were dietary deficiency diseases a problem. However, in the Orient, where polished rice formed the main staple of the diet, beriberi was a common and debilitating disease, and in our own southern states, where corn and pork comprised the sole diet of certain impoverished communities, pellagra was often widespread. Clearing up such pressing problems as these brought the vitamins dramatically into the limelight. Today the problem is probably not less pressing but less dramatic.

Water-soluble vitamins are often cooked out of vegetables, even when quite fresh, and a small amount of cold storage depletes the vitamin content of vegetables and fruits. Moreover, the whiter parts of the leafy vegetables are more palatable than the green outer leaves which are often discarded. Thus the housewife unintentionally but efficiently deprives her family of the full vitamin content of food. The fatiguing effects of dietary deficiency are less easily brought before the public mind, but since it has been proved that much of the nervous fatigue of adult life is due to a lack of vitamin B_1 and that some errors in vision which may make night driving unsafe are due to a lack of vitamin A, it becomes necessary to launch a widespread program of education. To this end the American Medical Association in 1940 favored the addition of vitamin B_1 to milled flour and to processed cereals. This was extended in 1941 by the United States Food and Drug Administration to include the pellagra-preventing factor, niacin, together with some iron for blood building.

Thus the American public can be sure of getting vitamins in flour, cereals, and baker's bread, but the whole problem will not be solved that easily.

Vitamin A (Beta-Carotene).—Vitamin A is a fat-soluble vitamin which can be synthesized in the liver through the action of enzymes on its precursor, *carotene*.

Presence of vitamin A is essential to an adequate supply of visual purple on the retina of the eye.

Sources:

Food—butter, egg yolk, carrots, corn, sweet potato, apricots.

Medical—all fish liver oils.

Daily requirement:

4,000 U. S. P. units.

Deficiency:

Xerophthalmia, a disease of the eye resulting in dryness of the eyeball.

Night blindness, a weakening of the adaptation of the eye to darkness; may follow even a slight deficiency (since bright lights tend to destroy visual purple, many night auto accidents may be traced to a deficiency in vitamin A).

Suggested uses:

Resistance to nose and throat infections resulting in common colds has been increased by treatment with vitamin A.

Color vision improved; experiments on color-blind men show that fewer mistakes in color detection follow treatment with vitamin A; improvement is temporary and depends on the rapid regeneration of visual purple.

Vitamin B Complex.—The designation B covers all vitamins found in the wheat germ and in yeast, and the number of factors in the complex is greater than all the rest of the known vitamins. The B vitamins are all water soluble, but not all have the same reaction to heat. They are classified as *thermolabile* and *thermostabile.* The thermolabile group is more easily boiled out of foods in ordinary cooking than the thermostabile group.

THERMOLABILE GROUP

Vitamin B_1 (thiamine), popularly known as the *morale vitamin.* Presence of vitamin B_1 is essential to the completion of the oxidation processes of metabolism. Oxidation stops at an indeterminate stage in the absence of thiamine.

Sources:

Food—wheat germ, yeast, most meats, egg yolk; now available in enriched flour and in many processed cereals.

Medical—available in tablet form under various trade names.

Daily requirement:

2,000 micrograms.

Deficiency:

Beriberi, or polyneuritis, a disease of the nervous system common in the Orient where the diet consists to a large extent of polished rice.

Many disorders of the adult nervous system such as neuritis, neurasthenia, and nervous fatigue; this is traced to a preference for refined foods, canned foods, and to cold storage.

Suggested uses:

Thiamine has been used to overcome the depressive effects of tropical heat and is suggested to relieve the effects of the severe heat in boiler and furnace rooms and even the effects of severe heat waves in cities.

Experimentally is has been used to relieve the pain in the disease of the trigeminal nerve known as *tic doloreux.*

It is believed to be essential to the function of the liver in inactivating the female hormone, estrogen, which has been the cause of cancer in some cases in later life; also stimulates the intestinal muscles and the appetite and so improves general well-being.

(Thermolabile factors of no known value to man are not listed.)

THERMOSTABILE GROUP

Vitamin B_2 (Riboflavin), a respiratory catalyst; essential to the synthesis of certain oxidation enzymes; formerly confused with the pellagra-preventive factor.

Sources:

Food—wheat germ, yeast, most meats but especially liver and kidney, milk, eggs, green and leafy vegetables.

Daily requirement:

2,000 micrograms.

Deficiency:

Keratosis, blindness due to the growth of blood vessels on the cornea, destroying its transparency.

Niacin, a vitamin without a letter designation; it is the specific antipellagra factor, P-P, of Goldberger, and vitamin G of Sherman. It was isolated as *nicotinic amide* from liver in 1938 by Elvehjim.

Sources:

Food—wheat germ, yeast, liver and kidney, beef, buttermilk, green peas, rice polishings, and turnip greens; now available in enriched flour.

Daily requirement:

10,000 micrograms recommended but not standardized.

Deficiency:

Pellagra, a disease involving skin lesions and a general lassitude; a complex disease common in certain impoverished communities of the southern states where the diet is limited to corn and pork as staples; it is probable that the entire B complex is in some way involved in its course, for, while certain specific symptoms of the disease disappear with niacin treatment, there may remain the skin lesions of the mouth and nose specifically attributed to a lack of riboflavin, and a fatigue in part attributable to a lack of thiamine; combining the three elements may accomplish a cure slowly, but rapid and dramatic recovery from lassitude and fatigue is accomplished only when an additional B vitamin is administered, B_6.

Vitamin B_6 (pyrodoxine), an antidermatitis factor in rats which in man has shown a definite relation to insomnia, lassitude, and irritability; acts as a coenzyme with amino acid decarboxylases.

Sources:

Food—wheat germ, yeast.

Deficiency:

Defects in protein metabolism, specifically the metabolism of the amino acids, tryptophane and tyrosine.

Recommended uses:

If added to vitamins B_1 and B_2 and niacin, it causes immediate recovery from lassitude and fatigue, often in less than twenty-four hours.

Pantothenic acid, a vitamin believed to be essential for all life.

Sources:

Food—wheat germ, yeast, liver, eggs, milk.

Medical—calcium pantothenate in tablet form.

Deficiency:

Dark hairs in piebald rats turn gray in eight weeks when pantothenic acid is omitted from the diet.

Suggested uses:

It has been used to speed recovery of patients after severe germ diseases, in which vitamin stores have been depleted.

Experimentally it has been used in attempts to restore pigment to graying hair in man; the varied degree of success reported in these experiments may depend upon the cause of the graying hair, which has not been determined in any of the experiments.

It has been suggested that the effect of pantothenic acid on graying hair depends upon a balance with other chemicals, one of which, para-amino-benzoic acid, may or may not prove to be a vitamin.

Choline, a vitamin with an affinity for fats which prevents long-continued fat infiltration characteristic of cirrhosis of the liver.

Sources:

Food—wheat germ, yeast.

Deficiency:

Causes liver cirrhosis in rats. May be a factor in the development of liver cirrhosis which accompanies diabetes and chronic alcoholism.

Suggested uses:

Choline with another chemical, cystine, has been attributed with the power to protect from cancer as well as to cause it; whether its action is protective or otherwise seems to depend upon a delicate balance of chemicals.

Extrinsic and Intrinsic Factors.—An intrinsic factor normally present in the stomach tissues is essential to the use in the body of an extrinsic factor in the food.

Sources:

Food—liver and yeast.

Deficiency:

Lack of the extrinsic factor causes pernicious anemia; believed to be a copper compound, normally found in liver; both factors are essential to the cure of anemia.

Vitamin C (Ascorbic Acid).—Vitamin C is a water-soluble vitamin apparently synthesized by all animals except guinea pigs, monkeys, and men.

It increases the strength of capillary walls.

Sources:

Food—all citrous fruits, spinach, milk, fresh vegetables.

Medical—available in tablet form.

Daily requirement:

600 U. S. P. units.

Deficiency:

Scurvy, a disease once common among sailors on long sea voyages where fresh fruits and vegetables were unavailable.

Capillary hemorrhage due to weakening of the walls may cause skin lesions and decrease resistance to infection.

Vitamin D.—Vitamin D consists of two fat-soluble sterol derivatives.

Vitamin D (Ergosterol).—The chief sterol of animal fats is cholesterol; in cholesterol is an activatable provitamin which, on exposure to ultraviolet rays, causes ergosterol to crystallize into another sterol derivative, calciferol; this is vitamin D_2. The provitamin is produced in the skin, hair or feathers, and is irradiated by sunlight.

Vitamin D_2 (Calciferol).—The crystallized form of the sterol is essential to the normal absorption of calcium and phosphorus from the intestines; it also causes the kidneys to return phosphorus to the blood; thus the vitamin assures a normal amount of calcium and phosphorus in the blood for bone building; it does not act on the bone tissue itself.

Sources (Vitamin D_1):

Food—milk.

Medical—cod liver oil, halibut liver oil.

Sources (Vitamin D_2):

Food—the crystallized vitamin is available in irradiated milk.

Medical—irradiated oils are available in the form of viosterol.

Daily requirement:

400 U.S.P. units.

Deficiency:

Ricketts, a disease of infancy in which the growing bones do not contain sufficient calcium and phosphorus for normal hardening; often results in a bow-legged condition if infants learn to walk with too soft bones.

A sufficient supply of calcium in the food is as essential as the vitamin. This can be assured by adding lime water to milk.

Modern living conditions in cities often deprive infants of the necessary sunlight for irradiation of ergosterol; therefore, regular use of irradiated milk or irradiated oils is advisable.

In the case of broken bones (except in infants) an excess of calcium appears to hinder the healing process rather than to speed it and medication with irradiated vitamin D and calcium is not advisable.

Vitamin E (Alpha Tocopherol).—Vitamin E is a fat-soluble vitamin essential to the fertility of rats and chicks. In human beings it is essential to the maintenance of nervous and muscular tissue and has been used with success in cases of frequent abortions. It is not a cure for sterility.

Sources:

Food—wheat germ oil.

Medical—dried whole wheat germ.

Deficiency:

Wasting of muscular tissue.

Suggested uses:

Fresh dried whole wheat germ has proved a successful cure for several types of muscular disease; a diet rich in vitamin E may increase resistance to such diseases as infantile paralysis.

Vitamin H (Biotin).—Vitamin H is one of the essential respiratory vitamins, functioning in intermediate carbohydrate metabolism. It is a specific cure for a certain egg white injury and is found in greater quantities in embryonic cells and in cancer and tumor cells than in normal tissues.

Sources:

Food—liver and yeast.

Deficiency:

Injury from fresh egg white, due to the absence in the tissues of the respiratory vitamin; the cause of the injury lies in the effect of the fresh albumin on the biotin in the food; the toxic quality in the albumin combines with the biotin, forming avidalbumin; this inactivates the biotin and causes the injury; the toxic qualities of the albumin are destroyed by coagulation so that cooking the egg prevents the injury.

Suggested uses:

The high content of biotin in embryonic and cancer tissues suggests a difference in metabolism in rapidly growing tissues.

Vitamin K (Phthiocol).—Vitamin K is found in fat-soluble form in the green tissues of plants (Vitamin K_1) and in water-soluble form in some bacteria (Vitamin K_2). It is essential to the formation of prothrombin in the blood. As prothrombin is essential to the formation of thrombin, it promotes clot formation. The vitamin is one of several antibleeding chemicals now being used to control hemorrhage.

Sources:

Food—any fresh green vegetable (it is probable that the tissues normally synthesize the vitamin so that presence in the diet is not necessary).

Medical—the vitamin can be administered in fat-soluble form by mouth but must be accompanied by bile salts; in the absence of bile salts the vitamin cannot be absorbed.

In water-soluble form the vitamin can be injected directly into the blood; this is a much more effective method, especially with infants or very sick patients.

Deficiency:

A low prothrombin level causes bleeding in infants; this is especially dangerous during the first four days of life.

Suggested uses:

The vitamin is an effective agent in controlling hemorrhage by hastening the formation of thrombin.

In the disease obstructive jaundice, there is a deficiency in vitamin K because of the absence of bile salts in the intestine; patients with such a condition have a tendency to bleeding.

The relation between the vitamin and prothrombin formation shows certain similarities to the action of a detoxifying chemical on cancer tissues. It is suggested that a normal prothrombin level may be a protection against cancer agents.

Vitamin P (Citrin; Eriodictyol).—Vitamin P is another vitamin useful in controlling hemorrhage, especially in infants with weak capillaries.

Source:

Lemon peel and, to a lesser extent, lemon juice; also in paprika.

Recommended uses:

This vitamin is closely related to vitamin C and may be a factor in helping the body retain C.

(Other vitamins have been identified but as they have as yet no known uses in man they have not been included.)

Energy

Energy is defined as the capacity to do work. It may also be defined as that which diminishes when work is done by an amount equal to the work so done. Any form of energy can be transformed into any other, but with every unit of work done an equal amount of energy returns to an inactive or potential state. The greater part of the energy transformed into heat will be waste energy since heat radiates into colder bodies and ceases to do work. Since all energy release is accompanied by some heat, a great deal of the available energy is constantly becoming useless to living organisms. It is necessary, therefore, that the organisms capture the energy coming in from the sun. This is accomplished by the chlorophyll bodies of the green plants which absorb light rays during photosynthesis and so make the energy available to the organic world.

Heat.—Some heat is produced wherever energy is expended. There is less in plants than in animals, for energy is expended only for growth of cells. However, a measurable amount of heat does accompany respiratory activities in plant cells and this shows a definite relation to the rate of respiration. Usually this heat is removed by transpiration or conduction and no noticeable rise in plant temperatures occurs. In some cases of fermentations, however, where hay and sawdust in piles are attacked by bacteria, the temperature of the plant cells may increase to the point where it will ignite the fermentation products of the bacteria. Under too high oxygen concentration plants can be killed by internal heat from too vigorous oxidation.

In animals large amounts of heat are produced. Some of this heat is used to maintain an internal temperature. In aquatic organisms and in cold-blooded vertebrates that is about the temperature of the surrounding medium. In birds and mammals, however, the internal temperature is maintained at a very constant level throughout life. This has been made possible by the long and gradual structural adaptation of vertebrates to life on land. The completely four-chambered heart separating the blood to the lung from the body circulation, and the development of sweat glands in the skin of mammals were factors in temperature control. On warm days the sweat glands excrete copiously, but on cold days very little; thus the amount of heat lost is regulated. In small mammals where there are no sweat glands, the fur helps to retain heat; in birds, the feathers help to retain heat. In hot weather, air radiates between the feathers and the skin with a cooling effect. In cold weather the feathers cling close to the body and prevent the circulation of air.

Body heat comes from the oxidation of food products. Dextrose is the universal source of energy in both plants and animals, but in the processes of metabolism fats and proteins are oxidized also. The oxidation of any given amount of a product will always produce the same amount of heat. Therefore, this can be measured exactly. The physiologic unit is the Calorie. This is the amount of heat required to raise 1 kilogram (1,000 grams) of water 1 degree Centigrade. In the small calorie used in physics, 1 gram is the amount used instead of 1,000.

By burning food materials and excreta in a furnace known as a *bomb calorimeter,* the number of heat units produced by burning 1 gram of a substance can be determined with accuracy.

Fat (average)	9.3
Carbohydrate (average)	4.1
Protein in body	4.1
Protein in bomb calorimeter	5.6

The discrepancy between the protein units from the food and the protein used in the body is accounted for in the partial oxidation products of proteins, urea, uric acid, and creatinine. Many of the proteins are deaminized in the liver before reaching the tissues. The ammonia (NH_3) released is synthesized into urea in the liver and exerted by the kidneys. The remaining portion is a carbohydrate which is completely oxidized. Creatinine and uric acid are also excreted by the kidneys. When these partial oxidation products are considered, the discrepancies disappear.

For convenience in working out food values for diets it is conventional to omit the decimals. The Calories produced by 1 gram of fat is 9; carbohydrate, 4; protein, 4.

Mechanical Energy.—Motion is a form of mechanical energy by which animals respond to stimuli. Essentially it is a function of contractility. The flagellum of the unicellular organisms are contractile at the base. Cilia are of the same construction but are more minute and many contract in unison. Even pseudopodial formation involves a contractile process (see page 165).

In the simpler tissue animals the function of contraction is concentrated in contractile cells. Later, muscle cells combined into fibers and bundles of fibers until whole muscular layers were formed. In the vertebrates a complex muscular system accomplishes the movement of one part on another, as well as the propulsion of the entire animal.

Plants exhibit very little motion. There is a motion caused by rapid turgor changes as when the leaf blades of a Venus flytrap close over an unwary insect. In the majority of plants, however, motion is accomplished by the differential growth of cells and is noticeable only over a period of time.

The energy of motion is a transference of chemical energy.

Chemical Energy.—The term chemical energy is applied to that form of energy released by the *exothermal* processes of metabolism which causes a contructive *endothermal* process to take place. The chemical transformations that accompany muscle contractions are a good example. There is in muscle normally a supply of glycogen and a supply of phosphocreatin which permits a muscle to contract instantaneously on stimulation, even in the absence of atmospheric oxygen. Continued activity, however, depends on an ample supply of oxygen. The chemical activities involved are briefly outlined here.

1. When the muscle is stimulated, the phosphocreatin is hydrolyzed into phosphoric acid and creatine. The process is exothermal and the energy released causes the muscle to contract. No oxygen is required for the process.

2. Glycogen then undergoes a partial hydrolytic cleavage forming lactic acid. This is an exothermal process and the chemical energy released is utilized to recombine the phosphoric acid and creatine into phosphocreatine. This is an endothermal process. No oxygen is required.

3. The resynthesis of glycogen from the lactic acid molecules cannot take place in the absence of oxygen and involves two steps.

(a) A part of the lactic acid is oxidized into carbon dioxide and water. The atmospheric oxygen of respiration is the oxidizing agent. The process is *exothermal.*

(b) The energy released by the oxidation of the lactic acid causes some of the remaining lactic acid to resynthesize into glycogen. This process is *endothermal.*

Accumulation of excess lactic acid in the muscles causes fatigue. Continued aeration of the muscles by respiration is necessary, therefore, for continued muscular effort and for recovery from fatigue.

Electricity.—Small amounts of electrical energy are produced in every protoplasmic cell. This is due to the electrolytic dissociation of the electrolytes present, causing positive ions (*cations*) and negative ions (*anions*). Stimulation causes a change in the permeability of the plasma membrane. In the unstimulated cell only hydrogen$^+$ ions (cations) can pass through, the larger OH^- anions being held inside. Because the interior of the cell is electronegative, the H^+ ions are held in the immediate vicinity of the membrane and form an electropositive layer immediately outside the cell. Thus the cell at rest is always electronegative to the medium outside of the cell.

On stimulation, bioelectric currents are set up inside the cell. These are known by various names—*action* current, *blaze* current, etc. They involve a temporary change in the permeability of the plasma membrane. Experimentally a stimulation may be caused by the approach of a cathode to the plasma membrane. It seems possible that this approach causes a tilting of the sandwich-like layer of the membrane so that larger ions can slip through. These may be the anions of lactic acid. When they slip out, they leave the cell electrically neutral.

The outward diffusion of the organic anions helps spread the stimulated area and tilts the sandwich-like layer still more, drawing out more anions. This process will continue until the redistribution of cations and anions has made the whole cell and medium electrically neutral. The sandwich layer will then tilt back and the plasma membrane becomes impermeable to organic acid anions. Since these have been lost to the cell by diffusion, the electrical negativity of the cell interior can be regained only by the synthesis of more lactic acid and the outward diffusion of more hydrogen ions. When that has been accomplished, the cell is capable of stimulation a second time.

Tissues in which stimulating agents set up bioelectric currents which bring definite responses are called *irritable tissues.* The cause of the currents is the plasma membrane. Conduction of the charges is accomplished by the salt solutions that surround the cell. That bioelectric currents account in some way for the movement of chromatin granules during mitosis is quite probable. The threads of the spindle behave morphologically as do iron filings in a magnetic field. Chromosomes are attracted first to the equator where their electric potential becomes altered and the halves repel each other, moving to opposite poles.

Galvani, an Italian anatomist, discovered the presence of an electrical change in the muscles of frogs' legs when he was working in his garden. The current produced, now known as the demarcation current, can be illustrated by laying the nerve of one muscle on the injured (permeable) surface of another. As the nerve touches the injured surface, the uninjured muscle will contract, for the cut surface of any tissue is always electronegative to the uninjured portion. Currents set up in the injured muscle, therefore, are transmitted to the nerve of the uninjured muscle. All the present knowledge of voltaic electricity started from this chance observation.

The electric potential difference in any cell is never more than about 0.1 volt. In certain fishes, however, the muscle cells have become modified so that they are arranged in series to serve as electric organs, and in these animals the electrical current passes out into the water which acts as a conducting medium. These fishes are thus able to send shocks to a considerable distance, and the shocks are sufficient to stun other animals into activity while the more sluggish electric fish approaches to eat its prey. The power of fishes to give electric shocks was known to the ancients, although the nature of the shock was not determined until late in the eighteenth century. A hieroglyphic representation of the electric catfish has been preserved on the Egyptian tomb of Ti, and the still more formidable shock of the Mediterranean electric ray, Torpedo, was used by Roman physicians in the treatment of patients. The numbing power of the South American electric eel has long been known, and it has been said that horses have been

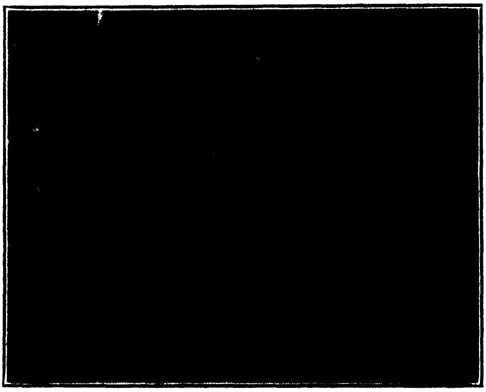


Fig. 102.—Electric organ of Astroscopus. Photomicrograph of section through head of 20 mm. embryo (×80). To show the relation of the electric area to the eye muscle. *El*, Electric area; *R. Ex.*, rectus externus muscle; *R.Su.*, rectus superior muscle; *A.*, artery; *III*, third cranial nerve which innervates the electric organ. (Photograph by author. First published by the Carnegie Institute.)

killed by these shocks when driven into shallow waters to drink. On the coast off the southern United States fishermen have often been shocked by the stargazer which lies buried in the sands.

All of these phenomena have been traced to definitely constructed electric organs, and the shock can be measured with a galvanometer. On microscopic examination the organs prove to be veritable batteries in which the cells are arranged in series (linear columns). In nearly every case investigated the cells are modified muscle cells, elongated into narrow, polarized plates. By experiment it has been determined that the plasma membrane is disrupted first on the cell surface where the nerve touches and stimulates the cell, the opposite side remaining electropositive as is the whole surface in the resting cell. In Malapterurus, the electric catfish, it is claimed that the organs develop from the skin glands, but this is doubtful. The probability is that the smooth muscle cells contribute to this structure.

In connecting up battery cells, the positive pole of one may be joined by a wire to the negative pole of the next, the resulting electromotive force being equal to the sum of the voltages of all cells in the series. If joined by similar poles, however, positive to positive, the negative to negative, the electromotive force will be equal to that of one cell only, but the current will be increased. By the former arrangement batteries are said to be arranged *in series,* by the latter, *in parallel.*

In the electric organs the cells are arranged with the positive pole of one cell against the negative pole (portion stimulated by the nerve) of the next, so that the voltage of the shock is relative to the number of cells in the pile. There may be many such piles, however, and the piles may be considered to be arranged in parallel, while the cells in each pile are arranged in series. In this way the organ provides for both current and voltage. In those fishes in which the shock has been measured with the galvanometer the voltage of the shock appears to be relative to the height of the pile, i.e., to the number of cells arranged in series.

The salt-water electric fishes include Torpedo, the ray, and Astroscopus, the stargazer. In these forms the organs lie in the head, the current passing from the dorsal to the ventral surface. In Astroscopus the organ is formed in the embryo by the modification of the developing eye muscles which have been sacrificed at the expense of free eye movement.

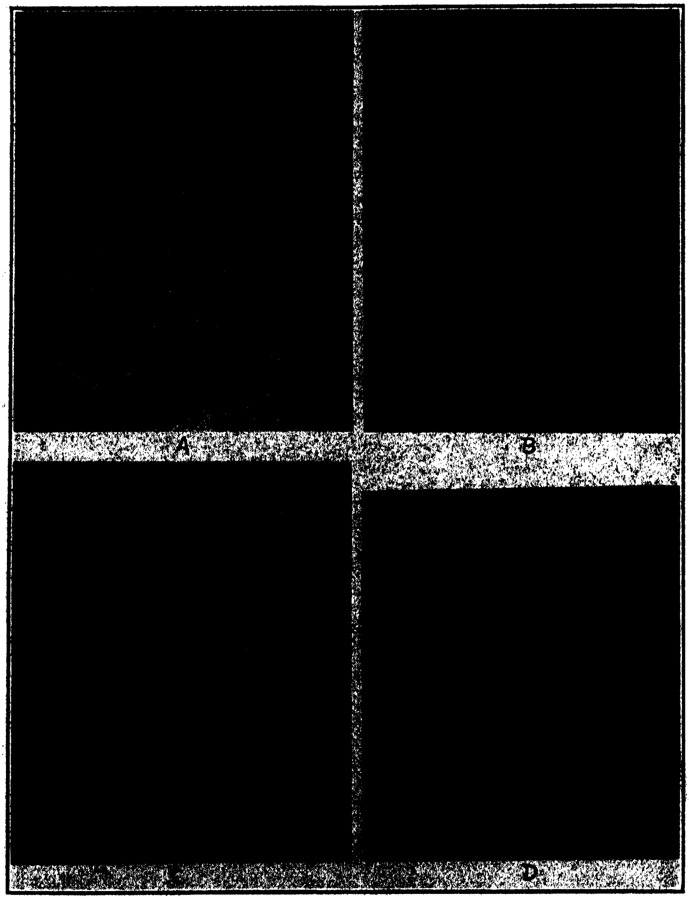


Fig. 103.—Electric organ of Astroscopus. Photomicrographs of sections through heads of 33 and 80 mm. embryos. To show the gradual differentiation of the electric area into polarized electric cells. The polarization is plainly shown in *D*. The cells are arranged in series. *A*, 33 mm. embryo (×35); *B*, 33 mm. embryo (×85); *C*, 80 mm. embryo (×35); *D*, 80 mm. embryo (×85). *R. Inf.*, rectus inferior muscle; *R. Su.*, rectus superior muscle (almost obliterated); *El.N.*, electric nerve. (Photograph by author. First published by the Carnegie Institute.)

In the fresh-water forms, such as Gymnotus, the eel, and Malapterurus, the catfish, the organs lie parallel to the sides of the body, an arrangement which makes possible a much larger number of cells in series. This is probably accounted for by the fact that salt water is a many times better conductor than fresh water, for it takes a much higher voltage, proportionately, to produce a stunning effect in fresh water than in salt water. In Gymnotus, the excessive length of the eel-like body accounts for the voltage of the shock which is greater than that of any other fish known.

All electric fishes are immune to their own shocks and to those of fishes of the same species, a condition analogous to that found in the viper which is immune to its own poison. No reason for either case is known.

There is no genetic relation to be traced between the diverse forms demonstrating the phenomenon. The ray is a shark relative, the most primitive type of fish; the stargazer is a specialized teleost, the highest type of fish known. The development of these organs must be looked upon, therefore, as parallel specializations to overcome the disadvantages of a sluggish habit.

No organism other than fishes has been demonstrated to give powerful electric shocks, probably due to the need of water as a conducting medium, and the peculiar adaptability of muscle cells to this type of performance.

Light.—The sun is continually sending out radiations of various wave lengths, and many of these reach the earth and provide a source of new energy. These are known as *electromagnetic waves.* Analysis shows them to be of different wave lengths and to be capable of different types of work.

If a beam of sunlight be allowed to fall on a prism, the light will be broken into its component wave lengths. Those visible to the human eye comprise the visible spectrum. These range from the longer red rays through the orange, yellow, green, blue, indigo, and violet. Further analysis shows that rays do not end with the visible spectrum but continue ad infinitum in either direction. The longer rays continue through the infrared heat rays to the still longer sound and radio waves. At the violet end they extend through the chemically active ultraviolet rays to the cosmic rays and eventually to the infinitely minute gamma, beta, and alpha rays (see Chapter XI).

The value to us of the heat waves from the sun can be seen in the changing temperatures of the seasons, and the value of the light rays, through the variations of the day and night. Once a month light rays from the sun come to us reflected from the moon and provide a soft illumination of the darkness of night.

The visible spectrum is known to us as color. Color is an interpretation made by the human brain of the effect the several wave lengths make on the sensitive cells of the retina. There is no reason to suppose that animals which do not possess these cells have any perception of color, since color blindness in man accompanies the failure in function of certain zones of the retina. Color-blind persons see the wave lengths to which they are not sensitive as a neutral gray.

Color affects the eye differently, depending upon whether the rays are *absorbed, refracted,* or passed through a *diffraction grating.*

When rays are absorbed, as in the chlorophyll of the green plants, the color we see is a combination of the wave lengths not absorbed. *Absorption colors* are known as *pigments.* They are found in the hemoglobin of the blood, in the skin pigments of vertebrates, and in pigments of bird feathers, wings of butterflies, and moths. In green leaves yellow and red pigments are frequently masked by the chlorophyll but give color to the leaves when the photosynthetic processes cease and the leaves dry in the fall. In seaweeds red and brown pigments may lie over instead of under the chlorophyll and so prevent the green color from showing.

Where pigment is on the surface it is usually protective, since it absorbs the light rays and prevents them from penetrating to the sensitive tissues underneath. In several species of animals the nerves are more or less covered with pigment, while in others a heavy pigmented coat lines the visceral cavity. These pigments may also be protective.

Albinism in animals is a condition caused by the absence of pigment in the skin cells. Human albinos, and to a lesser extent, persons with fair complexions, are much more susceptible to sunstroke than are those with darker skins. Thus more heavily pigmented peoples are more easily adapted to life in the Tropics, and white people living there tend to accumulate protective pigments as heavy coats of tan.

Refraction color is due to interference with the sun's rays by striking a surface which reflects them back. Such rays show a metallic color which changes as the exposure to the light changes. The brilliant lights on the throat and neck of the ruby-throated humming bird are due to this interference, while the colors on the body of the bird are the result of absorption. The metallic band, or *speculum,* which crosses the secondary wing feathers of ducks is a similar effect. The wings of the butterfly, Morpho, have a metallic blue color edged by a rim of brown pigment. Refraction of light rays helps to keep an animal cool.

Iridescence is due to diffraction of the rays, as when the light plays over a diffraction grating. Iridescence is seen in the opalescent tentacles of the tube worm, Cistenides, and in the striated cuticle of the earthworm.

Change of color as seen in the tree frogs and in chameleons is accomplished by the aggregation or dispersion of the pigment granules in the chromatophores in the skin cells. This can be demonstrated in the scales of the fish, Fundulus. Here, when the melanin pigment granules are dispersed a dark coloration results; when the granules are aggregated the fish has a silvery appearance.

In the mantle of the squid the pigment is not all in the expansible chromatophores. When the chromatophore muscles contract, the chromatophore is expanded and the pigment is spread out. A delicate iridescence in Sepia is due to iridocytes.

Bioluminescence

Bioluminescence.—Some animals and even a few plants transfer the energy released by oxidation into visible light rays. The firefly and the glowworm are familiar examples. The light which follows in the wake of a ship at night, or outlines the form of a swimmer, is animal light. The most common cause is the minute one-celled *Noctiluca miliaris.*

There is a jellyfish, *Pelagia noctiluca,* on which the whole surface of the umbrella can be made to glow by stimulation, and the granules which are secreted during the process can

Fig. 104.—A school of luminous squids, *Watasenia scintillans*, found in deep water off the coast of Japan. (Drawn by the author after descriptions. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

Fig. 105.—A luminous fish attacking squids which eject a luminous secretion. (Drawn by Bruce Horsfall after descriptions by Ulric Dahlgren. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

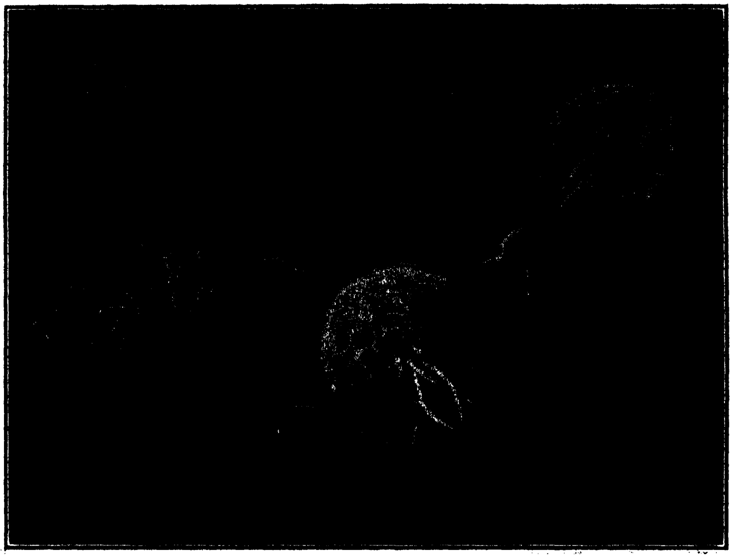


Fig. 106.—A luminous jellyfish, *Pelagia noctiluca*, from the Mediterranean Sea. (Drawn by the author from descriptions by Ulric Dahlgren. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

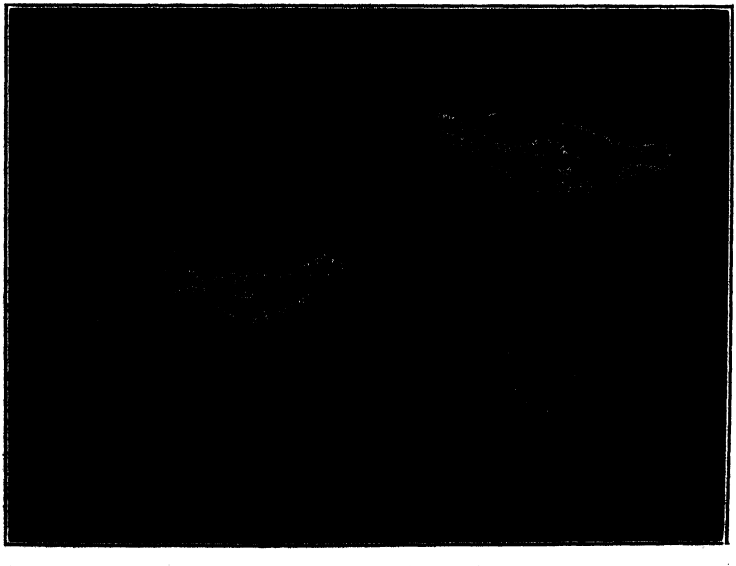


Fig. 107.—A luminous gastropod, *Phyllirrhae bucephala*, as it appears at sea when lighted. (Drawn by the author after descriptions. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

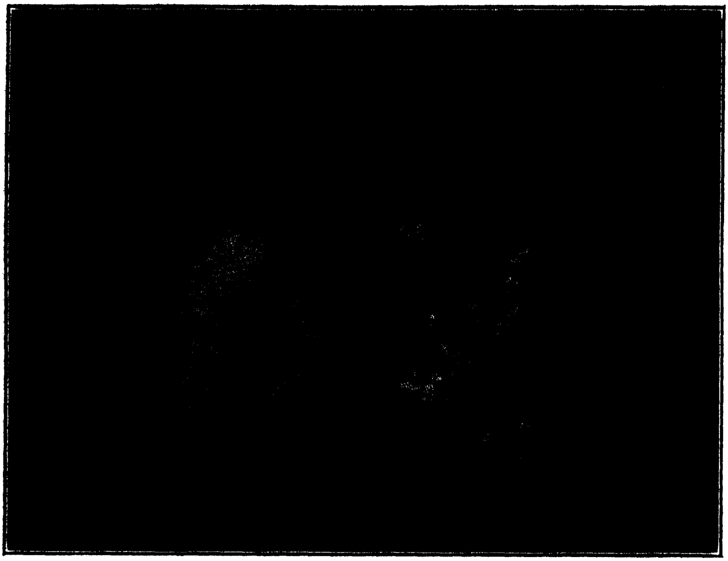


Fig. 108.—Two luminous fungi (*Clitocybe illudans*, left, and ***Panus stypticus***, right) growing on an old stump. (Drawn by the author from descriptions. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

Fig. 109.—Cultures of luminous bacteria grown on agar plates, and photographed in the darkroom. The luminescence serves to show up the skull between them. Copied from Molisch. (Previously published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

be removed on the finger where they will continue to glow, showing that the light is produced by the extrusion of these granules from the cells.

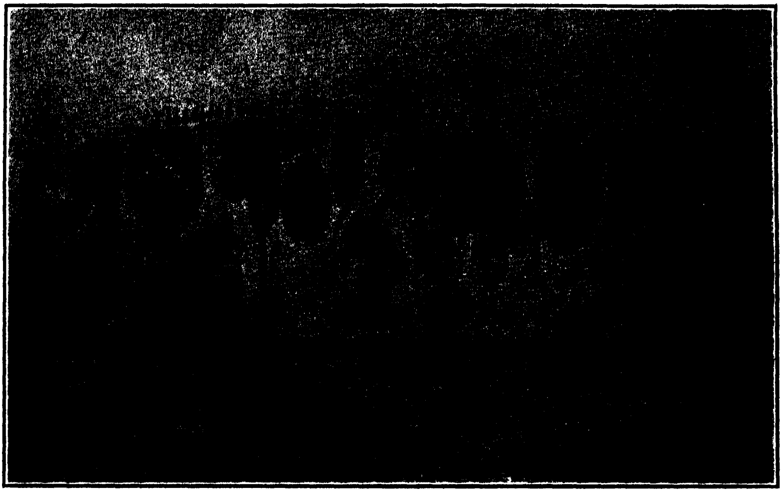


Fig. 110.—Section through a portion of the ex-umbrella of *Pelagia noctiluca,* showing several kinds of cells: *l,* luminous cells; *m,* mucin-secreting cells; *v,* empty cells from which the luciferine has been discharged. (Drawn by the author from a section. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

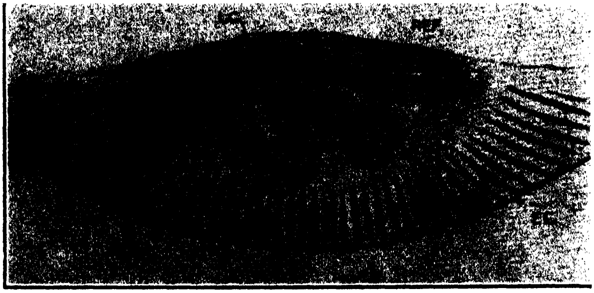


Fig. 111.—One of the light-producing organs of the squid. *Watasenia scintillans,* showing reflector. *EC,* outer surface of organ; *REF,* reflector; *LC,* luminous cells; *R,* rods. (Drawn by the author from a section. First published by Ulric Dahlgren in the Journal of the Franklin Institute. Reprinted by permission.)

In Pelagia the granules remain in contact with the surface, but the luminous shrimp and the octopus shoot the granules into the water, and in the minute *Noctiluca miliaris* they remain inside the cell. In many of the higher invertebrates, such as the squid, and in the fishes which have luminous organs, there are perfect lenses and reflectors which concentrate and reflect the glow.

There are a few plants which develop light. A mushroom which grows on the bark of trees emits a dull glow from its under surface, and there are putrefactive bacteria which glow. The latter phenomenon can be seen if a small fish is sealed in a glass jar until it putrefies. The surface of the fish can be seen to glow when the jar is opened in the dark. A steady, continuous glow of a greenish light is seen as long as oxygen is present. Where large colonies of the bacteria form, the illumination is sufficiently strong by which to photograph objects. As early as 1667 the phenomenon of light production was known, and Boyle discovered that oxidation was essential to the process.

Bioluminescence is the most efficient light known, only 1 per cent being invisible heat rays. It is, therefore, known as a cold light. The granules secreted by the luminous cells contain *luciferin.* This is the substance which glows, but the glow is activated by an enzyme, *luciferase.* Some stimulus activates the enzyme which acts as though a button were pushed to turn on the light. The reaction only occurs in the presence of oxygen. Luciferase is an oxidase which makes the oxidation possible.

CHAPTER XIII

SOME PROBLEMS OF THE CELL

Germ Cells

All living things, plant or animal, arise by division of a single cell which was derived by division from a cell of the parent. In the one-celled forms the cells all live independent lives. In the higher forms, the cells are united and differentiated into tissues. Two types of cells develop from the dividing egg: the *somatic* and the *germ* cells; a distinction made by Weismann in 1891.

The somatic cells become differentiated into the tissues of the adult. The germ cells are set apart and are entirely undifferentiated until mature, when a physiologic division of labor between the cells of the two sexes is established. The germ cell from which all others develop by division is called the primordial germ cell. It differs in no way from the egg cell which produced it, and, for this reason, retains the potentiality of producing the whole organism, a potentiality which is progressively lost by somatic cells as differentiation increases.

In all multicellular animals the germ cells are supported and nourished by somatic cells which form organs known as *gonads*. In the female these organs are the ovaries; in the male, the testes. In plants the tissues of the gametophyte accomplish a similar purpose.

Mature germ cells are *gametes*. The female gamete is an egg, or *ovum* (ovule in the plant). In the male it is a sperm, or *spermatozoon*. When the two gametes fuse, a *zygote* is formed.

The egg is the larger gamete, and is nonmotile. There is a considerable amount of cytoplasm surrounding the nucleus. Since the function of the egg may include the nourishment as well as the development of the embryo, the cytoplasm often contains yolk spheres. In the plant the endosperm tissue is developed for this purpose.

The sperm is minute and motile. It is practically devoid of cytoplasm only a small amount surrounding the nucleus. The sperm usually has a centrosome which initiates the formation of the first cleavage spindle. This is absent or invisible in plants.

The motility of the sperm is essential in bringing the two gametes in contact; therefore, the sperm is provided with one or more flagella for the purpose. In the sperm cells of animals these are known as the tails.

The sperm is laden with stored energy which cannot be replaced once it has been expended. This energy must, therefore, be held in abeyance until the sperm is in the vicinity of the egg, and secretions from the female are often required to release it. This increases the probability of the sperm reaching an egg during the limited period of its activity.

Fertilization is the process by which the nuclei of two gametes are fused to form a single nucleus, after which the cell is a zygote. Since each gamete contributes a nucleus but only the egg contributes cytoplasm, all hereditary characters must be carried by the nuclei. Since the organization of the cell is laid down in the cytoplasm, it follows that the egg determines the species of the individual, regardless of what sperm initiates development.

Since the nuclei contain *chromosomes*, and the chromosome number of a species is constant, it follows that a full complement of chromosomes cannot be contributed by the two gametes, or the chromosome number would be doubled in each generation. At some time in the life history of an organism, therefore, the number of chromosomes must be reduced to one-half, so that each gamete will contribute one-half, and the fertilization process will restore the species number. The species number is called the somatic, or *diploid* number; and the gametic number is correspondingly *haploid*.

The process by which the diploid number becomes haploid is called meiosis, or maturation, and the place in the life history where it takes place is the meiotic phase. Reduction occurs in one of two unusual mitoses, called the maturation divisions.

Three types of individuals are recognized according to the position of the meiotic phase in the life history.

Terminal Type.—In the terminal type the diploid number of chromosomes is found in all the body cells, and the haploid only in the germ cells. The maturation process may be initiated early in the life of the individual, but is completed only at maturity. The process of reduction, therefore, immediately precedes the development of the next generation. This is typical of all the higher animals and many of the Protozoa. A few thallophytes may have this type also.

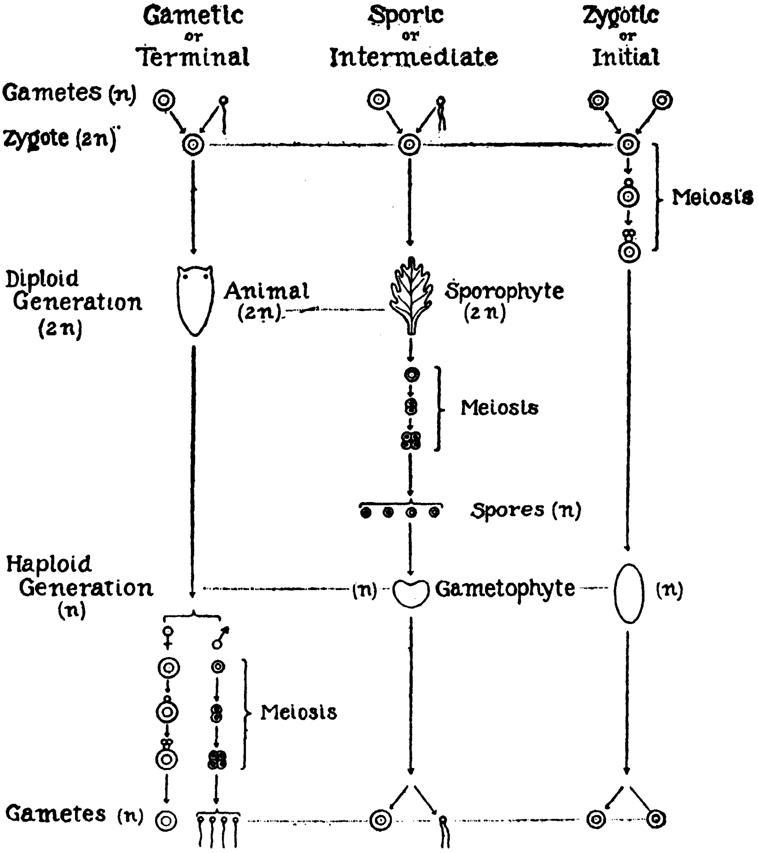


Fig. 112.—Diagram comparing the three known types of meiosis (maturation). (Reprinted by permission from Wilson: The Cell. Published by The Macmillan Co.)

Intermediate Type.—In the intermediate type there is an alternation of generations in which the organism of one generation carries the diploid number, and the alternating organism carries the haploid number. This is typical of all the higher plants and some thallophytes, but is unknown among animals.

The generation with the diploid number is the *sporophyte* generation; the one with the haploid number is the *gametophyte*. Meiosis occurs in the sporophyte in the *spore mother cell* which forms the spores. The spore has, therefore, the haploid number, and since the spore forms the gametophyte, all the tissues of the latter have the haploid number. The gametes are formed in the gametophyte by ordinary mitotic divisions.

Initial Type.—In the initial type, meiosis takes place at the beginning, rather than the end, of the sexual cycle, occurring immediately after the union of the two gametes. This type is rare, and is found only in a few simple plants and one-celled animals.

Maturation

The process of maturation is essentially the same in both plants and animals, except for the fate of the female cells. In the animal *polar bodies* are formed and discarded during the development of the egg; in the plant all the egg cells contribute to the formation of gametophyte tissues, and there is no material discarded. The details of the terminal type are given here. Those of the intermediate type would differ, not only in the absence of polar bodies, but also in the interpolation of a generation with tissues between the last maturation division and the formation of the gametes.

The maturation of the male germ cell is called *spermatogenesis,* and that of the egg, *oögenesis.*

Spermatogenesis

The primordial germ cell of the male, which is set apart early in the development of the embryo, is a completely balanced cell. From it develop by division hundreds or thousands of similar cells, called the *spermatogonia.* Each cell contains the diploid number of chromosomes.

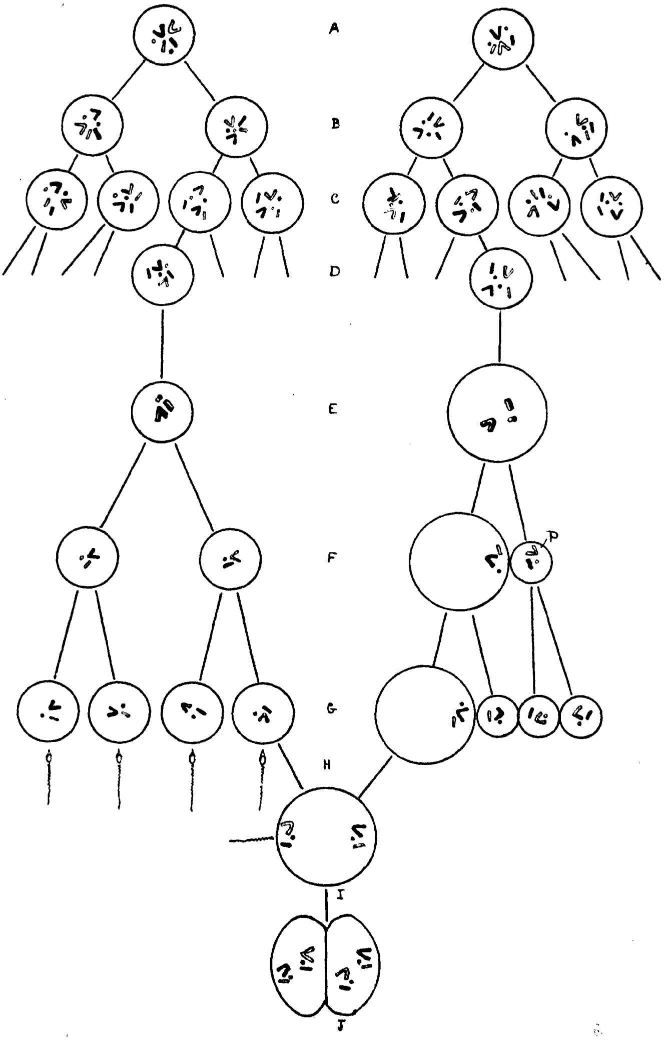


Fig. 113.—Maturation of the germ cells in an animal with three pairs of chromosomes. The shaded chromosomes represent the paternal chromosomes and the unshaded, the maternal. The male germ cells are shown on the left (spermatogenesis); the female, on the right (oögenesis). *A*, Primordial germs cells; *B, C, D*, spermatogonia and oögonia in an indeterminate number of divisions; *E*, primary spermatocyte and oöcyte with chromosomes united in pairs (synapsis), during a prolonged growth period; *F*, secondary spermatocytes and oöcytes following a reduction division in which random assortment of chromosomes takes place. The first polar body is formed (*P*); G, spermatids and oötid following an equation division. The second polar body is formed, and the first divided again, forming three; *H*, transformation of the spermatids into mature spermatozoa, each containing the haploid number of chromosomes; *I*, entrance of the sperm nucleus into the egg, prior to fertilization; *J*, first cleavage division, showing that each cell receives the same chromosome assortment as the fertilized egg.

At the approach of the meiotic phase the nuclei of the spermatogonia increase in size and undergo a reorganization of material. They are then called *spermatocytes.*

This reorganization period in the nucleus is comparable to a prolonged prophase of mitosis, but during this prophase chromosome pairs unite. The union is between homologous pairs of chromosomes which have been derived each from a separate parent. The union is only temporary, and none of the identity of the separate chromosomes is lost. The process is called *synapsis.*

At the end of the growth period the chromosome pairs shorten and thicken to form the prophase chromosomes, which assume characteristic shapes, such as rings, crosses, and figure of eights. These are *tetrads,* and the cell will contain the haploid number of tetrads, each representing a pair.

There then follow two rapid divisions, the maturation divisions. These differ from the ordinary mitoses, since in one of them the two chromosomes which have united will become segregated. In the other division the chromosomes will undergo an equal division, so that each tetrad will eventually form four chromosomes.

The divisions are known as the *reduction* division and the *equation* division, but species differ as to which occurs first. The result of the two divisions is four cells, each containing the haploid number of chromosomes.

The cell at this time contains a large amount of cytoplasm, and is called a *spermatid.* The *spermatozoa* are formed by the growth of a tail, the reorganization of the material into a head containing the nucleus and a small amount of cytoplasm, and a middle piece containing the centrosome. The excess cytoplasm is sloughed off during the process.

Oögenesis

The same process occurs in the female. The cells resulting from the divisions of the primordial germ cell are the *oögonia.* At the beginning of the growth period they become *oöcytes.*

The period of growth differs from that in the male since the growth of the nucleus is accompanied by the growth of the cytoplasm, and often by the accumulation of yolk. Synapsis occurs as in the spermatocyte.

The history of the oöcyte differs from that of the spermatocyte in the increased bulk of the cell and in the consequent limiting of the maturation divisions to the nucleus. The divisions follow as in the male, but one of the dividing pair is pinched off the side of the egg as a *polar body*. In the second division, the first polar body divides simultaneously with the nucleus, so that when the second polar body is pinched off there are three discarded cells outside the egg.

The *oötid* contains the haploid number of chromosomes and becomes a mature *ovum* without further metamorphosis.

In some species the polar bodies form before fertilization, but it is more usual for the eggs to remain in the primary or secondary oöcyte stage until after the sperm has entered the egg, when the nucleus goes through the remaining division, or divisions, rapidly while the sperm waits at one side.

The most significant part of the process just outlined is the reduction of the chromosomes from the diploid to the haploid number, thus assuring a restoration of the normal number by fertilization.

Fertilization

The fertilization of Nereis is typical of those forms in which the polar bodies are not formed until after the entrance of the sperm. Nereis is a darkly iridescent worm which swims with a spiral movement through the water. When Nereis becomes sexually mature, the posterior end of the worm becomes differentiated from the anterior end and breaks off. This is known as the heteronereis. The sexes are separate. On a full moonlight night these heteronerei come to the surface in swarms. The rhythmical effect of the moon on many animal phenomena has often been noted. In the Japanese palolo worm which is a close relative of Nereis, there is an even more striking sexual phenomenon.

These worms come to the surface at midnight on the night before the new or the full moon in the middle of December and not at any other time of the year. They have been described as covering the water as with a sheet, thick down to the depth of a fathom. This at 1:00 A.M. At 2:00 A.M., not a worm was to be seen. These sexual rhythms involve internal changes which completely change the tropic responses of the individual during the mating season. The purpose of the phenomena is obvious. It brings about the meeting of the egg and sperm.

The secretions formed by the opposite sex are sufficient to cause the expulsion of the gametes. The active element is called *fertilizin.* In some eggs there is a special point, or *micropyle,* through which the sperm must enter and the successful sperm is the one which first finds that spot; but in many eggs, as in Nereis, any point can be entered, the sperm first piercing the outer cell wall being the successful one. It is for this that the *acrosome* is formed on the head of the sperm.

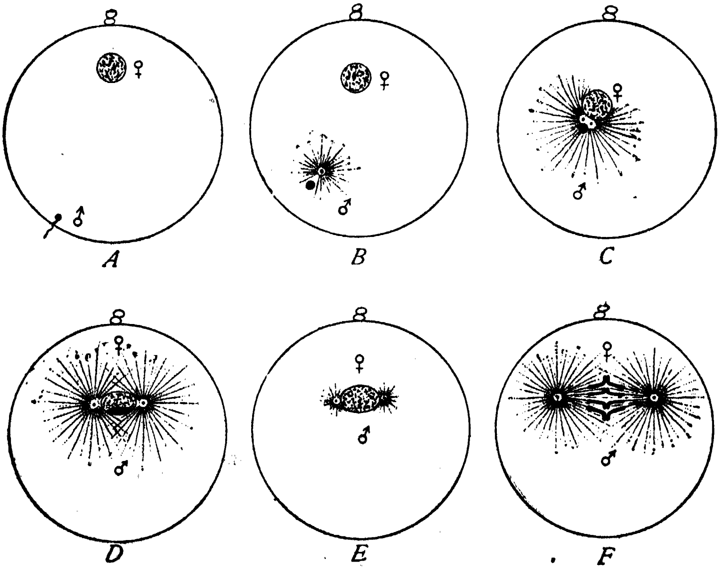


Fig. 114.—Diagram of fertilization as it occurs in the starfish. The polar bodies are thrown off before the entrance of the sperm. *A,* Egg with polar bodies attached, entrance of sperm; *B,* approach of pronuclei; *C,* division of sperm centrosome; *D,* fusion of pronuclei; *E,* reduction of asters in prophase preceding division; *F,* metaphase of first cleavage. (Reprinted by permission from Wilson: The Cell. Published by The Macmillan Co.)

Immediately after the sperm pierces the egg, the egg throws up a fertilization membrane, probably by the imbibition of water, which forces the other sperm away. Often the cell is surrounded by unsuccessful sperm which gradually drop off, never to function again.

The head and middle piece of the sperm enter the egg, the tail is left outside. This is not true in all forms, but the tail when it enters the egg, is absorbed by the cytoplasm. In Nereis the formation of the polar bodies starts immediately when the *fertilization membrane* forms. The sperm nucleus moves diagonally toward the center of the egg with the centrosome and amphiaster preceding. It waits in this position until the two polar bodies have been thrown off and then makes a sharp turn and moves directly toward the egg nucleus which also starts toward it. They meet in the center of the cell, as the first cleavage in Nereis is an equal division. Where they meet, they fuse, and the amphiaster of the sperm centrosome starts to form the spindle of the first cleavage. The position is determined by the axis of the egg, as the first cleavage divides the egg into right and left halves.

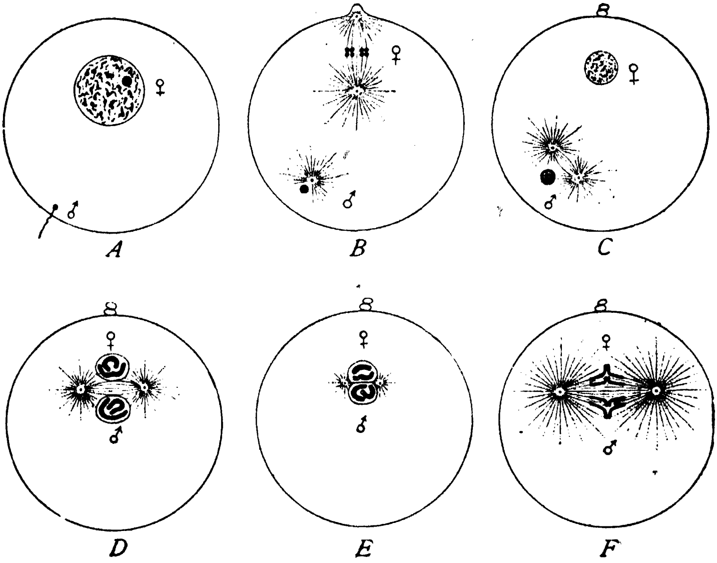


Fig. 115.—Diagram of fertilization as it occurs in Nereis. The polar bodies are not formed until after the entrance of the sperm. *A*, Immature egg; entrance of sperm; *B*, sperm aster and first polar spindle; *C*, polar divisions complete, division of sperm aster; *D*, approach of pronuclei, first cleavage spindle; *E*, reduction of asters during prophase preceding cleavage; fusion of pronuclei; *F*, metaphase of first cleavage. (Reprinted by permission from Wilson: The Cell. Published by The Macmillan Co.)

Cleavage

For typical cleavage, the starfish has been chosen, since in Nereis the cleavage is spiral, and it is more difficult to see the stages. The first cleavage passes through the axis of the egg, dividing it into right and left halves. Immediately after division the cells are flatter at the interface, but very shortly round up slightly. The shape can be easily demonstrated by soap bubbles which assume the same flat surface, at the interface between two bubbles. This is in accord with the law of surface tension (page 210) by which the surface of a plastic substance tends to occupy the least amount of space.

The second cleavage is at right angles to the first, but still passes through the axis. The third cleavage is at right angles to both the preceding planes, and is important because it separates the cells which will make the ectoderm from those which are destined to become endoderm. It is a more or less unequal division according to the amount of yolk in the egg, since cleavage planes pass less easily through cytoplasm which contains yolk. In the starfish there is comparatively little yolk, and the third cleavage shows only a slight differentiation between the cells of the upper quartet and the cells of the lower quartet. The succeeding divisions will be slower in the lower quartet than in the upper, since there is no yolk in the upper quartet.

There is no growth during the cleavage process; but the increased number of cells, and the pressure of the cells against one another, soon pushes them away from the center so that a hollow ball of cells is formed. This is the *blastula,* and the cavity is a *blastocoele.* The smaller cells at the upper pole are the ectoderm cells, and the pole marks the position of the adult head. The mouth of the embryo forms at the lower pole of the egg since it is here that the endoderm cells push into the blastococele to form the *archenteron* or embryonic digestive tract.

The process of inpushing is called invagination, and the two-layered embryo formed by the process is the *gastrula.* The embryonic mouth is the *blastopore.*

This completes the cleavage stages, as the animal is now an embryo. The main organization has been established, and from this time on the embryo will grow, and the cells will differentiate into the tissues and organs of the adult. The mesoderm in the starfish forms between the ectoderm and endoderm as pouches off from the digestive tract, and is, therefore, a derivative of the endoderm cells. In the animals of the teloblast series the mesoderm is formed from two teloblast cells which are derived from the endoderm.

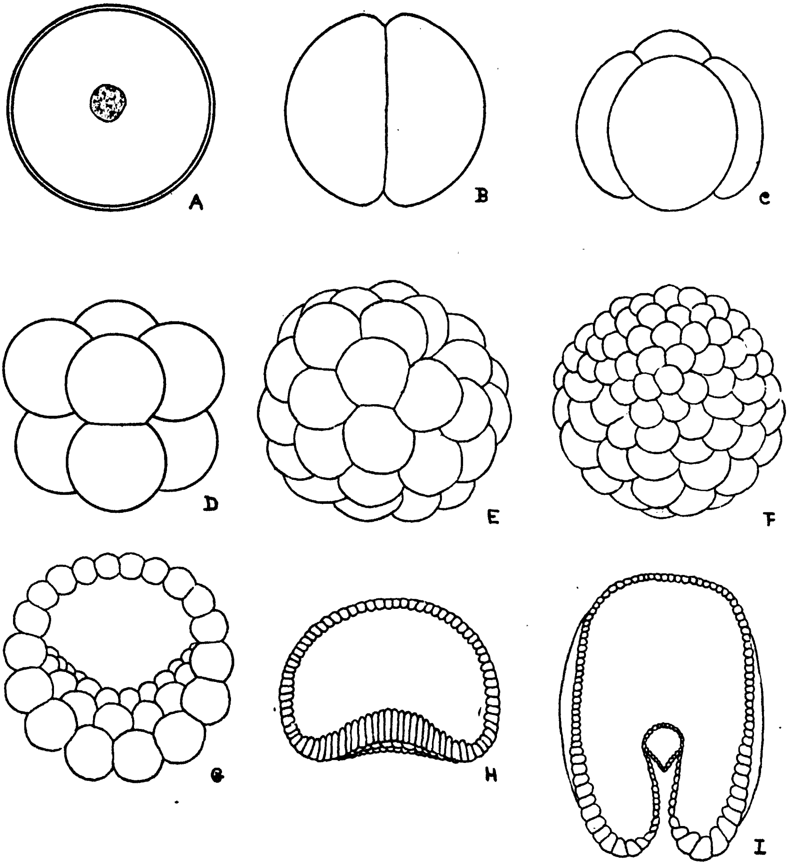


Fig. 116.—Cleavage of the starfish egg. *A*, Fertilized egg showing nucleus and fertilization membrane. *B*, *C*, *D*, 2-, 4-, and 8-celled stages; *E*, late cleavage stage; *F*, early blastula; *G*, cross-section of *F*; *H*, cross-section of late blastula; *I*, cross-section of gastrula. The differentiation into smaller (ectoderm) and larger (endoderm) cells is shown beginning with *F*.

The future history of the animal is the history of the three germ layers. The ectoderm gives rise to the external protective cells, to the nervous system, and the sensory areas of sense organs; the endoderm to the cells which line the digestive cavity and all organs which develop from it, such as digestive glands, and in the vertebrates, gills and lungs. The mesoderm supplies the material for all the other organs.

Parthenogenesis

Parthenogenesis is the development of an egg without fertilization. In all triblastic invertebrates where an alternation of generations is found, parthenogenesis is the typical means of reproduction alternating with the sexual. In the flatworms the liver fluke forms parthenogenetic eggs in the larval stage, and in the insects, the aphids, or plant lice, have a parthenogenetic generation.

In the cycle of the rose aphids, *Aphis rosa,* the tiny green plant lice especially adapted to rosebushes, the forms found on the rosebush in the summer time, are parthenogenetic females which lay eggs and continue to produce similar forms throughout the summer season. These lice have no wings. A drop of moisture often collects at the posterior end. This is the "honey dew" which ants find so delicious that they send out the captives in their colony to collect the dew. The lice are, therefore, known as the ant's cows. Collecting the honey dew in no way injures the aphid or interferes with its rapid multiplication which continues unchecked until the leaves begin to drop in the fall. It may continue throughout the winter if the bush is kept in a greenhouse.

The aphid has a sure antidote for failure in the food supply. The females lay eggs which differ from the parthenogenetic eggs in that some are male producing and some are female producing. The organisms which develop from these eggs are the sexual individuals and are supplied with wings. They mate and the female starts on an annual hunt for a species of witch-hazel bush in the bud of which it lays the *winter egg,* which has a hard shell to withstand the winter's cold. In the spring the larva hatches in the bud, eats its way through the fresh young tissues, and metamorphoses into a winged female which flies back to the rosebush and lays a parthenogenetic egg.

Another type of parthenogenesis is found in the bee colony where the males are developed from unfertilized eggs and the females from fertilized ones. The queen bee becomes fertile by a special process of feeding in the larval stage, the other females developing into the sterile workers of the colony.

Artificial Parthenogenesis

Some light has been shed on the factors of egg cleavage by the work on artificial parthenogenesis. It was the late Jacques Loeb who first caused complete parthenogenetic development to take place in the sea urchin egg (1899). Normal larvae were formed. He later was successful in rearing more than twenty parthenogenetic frogs through a complete metamorphosis by merely puncturing the eggs. In no other case has artificially stimulated development gone beyond the larval stage.

Two phases of the normal fertilization process must be successively stimulated in order to initiate development: the formation of the fertilization membrane which is normally raised from the surface of the egg upon penetration by a sperm head, and the actual cleavage process. The original method of Loeb involved two phases. First, the egg was treated with some substance which would raise the surface tension and thus release the fertilization membrane. Fatty acids were frequently used for this purpose. After the release of the membrane, the egg was placed in hypertonic sea water to stimulate development.

A variety of methods has been used successfully and these differ so widely that no conclusions can be drawn as to the phenomena which actually initiate this most vital of all processes in the egg. Passing an electric current through the water has been sufficient to start a frog's egg to divide, and stroking, puncturing, raising the temperature and shaking the eggs have all had the same effect. Acids have proved as potent as bases, and alcohols as ethers. Eggs seem, in fact, to be so ready for division at the time they are laid, that almost any stimulus will bring forth the response, and the presence of the sperm, although the usual stimulus, is not at all essential. The importance of the sperm in development lies rather in the maintenance of the chromosome number, and in the distribution of hereditary traits.

CHAPTER XIV

SOME PROBLEMS OF HEREDITY

LAWS OF MENDEL

Mendel, an Austrian monk, first discovered the facts now incorporated in the well-known Mendelian laws while experimenting with peas in the monastery garden at Brünn, Austria, in the middle of the nineteenth century. His success in plant breeding lay in his idea of selecting unit factors on the plants. All previous breeders had been misled by examining the plant as a whole and by choosing for experiment plants which showed a tendency to blend in inheritance.

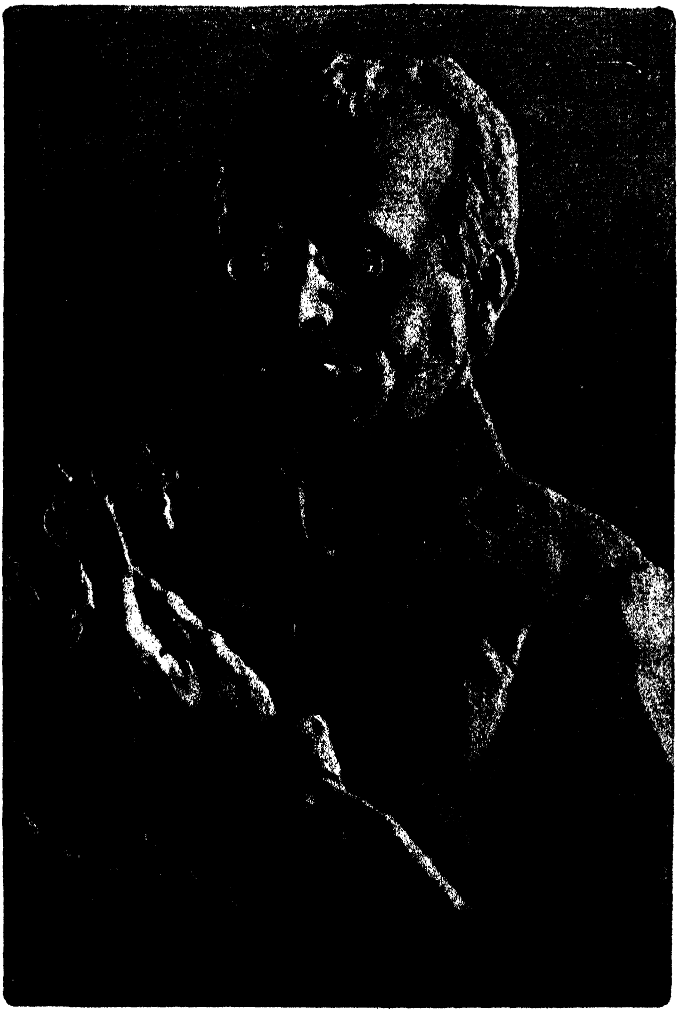
The results of Mendel's experiments were not known to the world during Mendel's lifetime (1822-1884), but in 1900, when the publications of the monastery were made public, they were rediscovered and recognized for their ingenuity. The papers were discovered simultaneously in three countries, Austria, England, and Holland, but it was Hugo DeVries, experimenting in a garden at Amsterdam, who put the laws to the test and amplified them by his own Mutation Theory.

The laws of Mendel involve two points: *dominance* and *segregation.* The law of dominance means that whenever two alleles of different expression, such as black and white, are united in an individual, the one, black, for instance, will dominate over the white, thus covering it up. The factor for black is then the dominant, and the factor for white the recessive allele.

The law of segregation refers to the habit of the alleles to separate into different gametes, and thus give opportunity for the recessive factor, hidden in one generation, to reappear in the next. By this law, the recessive reappears once in every four cases, and the distribution is parallel to the history of the chromosomes of which Mendel had not even heard.

A Monohybrid Cross

A monohybrid cross is one in which only one pair of factors is concerned. The cross made by Castle between black



Gregor Mendel

Fig. 117.—Gregor Johann Mendel (1822-1884). Plaque by Theodor Charlemont based on the "Fuschia picture" made between 1861 and 1864. The signature was inscribed at the close of an autobiography included in an examination for a teacher's certificate taken in 1850. (Courtesy of the Journal of Heredity.)

and white guinea pigs is a good demonstration of the principle. The unit factors of the guinea pig's coat are on separate chromosomes, and so show independent assortment.

Black is dominant over white. It is conventional to use large letters for the dominant factor, and small letters for the recessive alleles. This avoids confusion when many factors are to be considered. Thus B will represent the factor for the dominant black, and b the factor for the recessive white.

F_1

	B	B
b	Bb black	Bb black
b	Bb black	Bb black

F_2

	B	b
B	BB black	Bb black
b	Bb black	bb white

Fig. 118.—Checkerboards to illustrate a monohybrid cross. *B* stands for black and is dominant; *b* stands for white. The character expressed in the individual is named in each square. The F_2 proportion is 3 black to 1 white.

The Punnett square, or checkerboard, is used in the diagrams. The female gametes are placed on the top row, male gametes on the side, and the zygotes in the squares. Each zygote represents an individual, and in the checkerboard all possible combinations between the male and female gametes are represented. The characters expressed in the individual will be those represented by the capital letters present in the square. If no capital letter is present, the recessive factors are expressed. The factors represented by the letters in the square show what possibilities each individual carries, even though unexpressed.

The first generation is called the F_1 generation; the second the F_2, the third the F_3, etc. By the diagram in Fig. 118 it

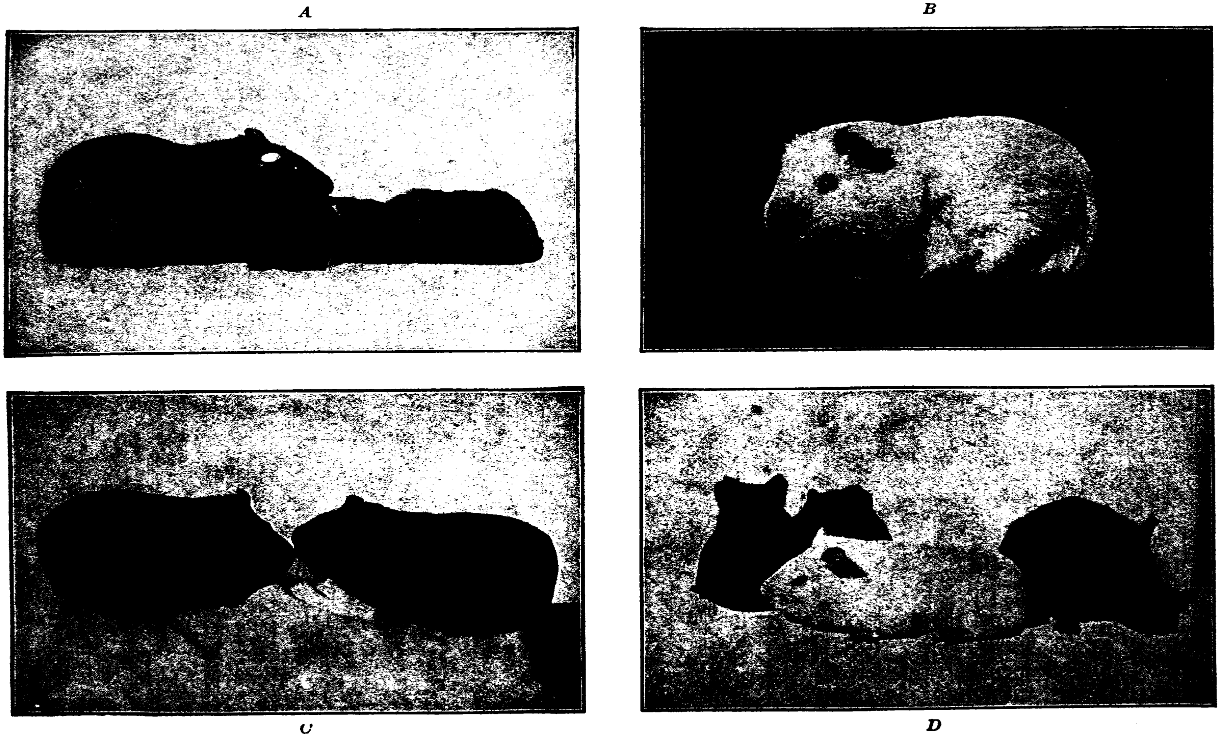


Fig. 119.—Photographs illustrating the cross between a black female guinea pig, and an albino sire. *A*, Pure-bred black mother and young; *B*, albino sire; *C*, young grown to maturity; *D*, second generation of young. (Reprinted by permission from Castle: Genetics and Eugenics. Published by the Harvard University Press.)

can be seen that all the F_1 hybrids have black hair. Among the F_2 guinea pigs there are three black-haired and one white-haired individual. This means that in any litter of as many as four this ratio may be expected. The larger the number of offspring in any generation, the more perfect will be the coincidence of actual and expected results.

A Dihybrid Cross

In a dihybrid cross two pairs of alleles are concerned in the cross. If to the coat color we add the factors for smooth and rough coats, there will be four possible combinations: black rough, black smooth, white rough, and white smooth. When there is free segregation in the germ cells, independent assortment of the factors will result, and gametes of all four kinds will be found.

The checkerboards in Fig. 120 show the F_1 and F_2 results. As rough is dominant over smooth the letter R is chosen, r representing smooth.

By reading the squares in the F_2 checkerboard it will be seen that the combinations will be represented in the proportions 9 black rough, 3 black smooth, 3 white rough, and 1 white smooth. The single factors may be considered separately, and will be found to be 3 black to 1 white, and 3 rough to 1 smooth.

A trihybrid cross can be made by adding one more pair of factors, in which case the number of possible combinations is increased to eight, and the F_2 expectations are, for every 64 zygotes, a ratio of 27:9:9:9:3:3:3:1, the three recessives occurring in the same individual only once in sixty-four times.

Mendel's original cross was made with peas, and the reason for his conclusions was simply the fact that in the peas no cases of linkage were present to modify the free assortment of factors, and each factor behaved as a unit. In the peas yellow was found to be dominant to green, round to wrinkled, and tall plants to short plants. Had the many modifications which have since been demonstrated existed in the peas, the results which have had such a profound influence on science would probably have been long delayed.

F_1

	BR	BR
br	BRbr black rough	BRbr black rough
br	BRbr black rough	BRbr black rough

F_2

	BR	Br	bR	br
BR	BRBR black rough	BrBR black rough	bRBR black rough	brBR black rough
Br	BRBr black rough	BrBr black smooth	bRBr black rough	brBr black smooth
bR	BRbR black rough	BrbR black rough	bRbR white rough	brbR white rough
br	BRbr black rough	Brbr black smooth	bRbr white rough	brbr white smooth

Fig. 120.—Checkerboards to illustrate the F_1 and F_2 expectations in a dihybrid cross. B = black, b = white, R = rough, r = smooth. Black and rough are dominant. The proportions of the F_2 individuals are 9 black rough, 3 black smooth, 3 white rough, 1 white smooth.

	IR	Ir	iR	ir
IR	IRIP white	IrIR white	iRIR white	irIR white
Ir	IRIr white	IrIr white	iRIr white	irIr white
iR	IRiR white	IriR white	iRiR red	iriR red
ir	IRir white	Irir white	iRir red	irir white

Fig. 121.—Checkerboard to show the results when two factors for white are present in maize, the one suppressing all color, the other recessive to red. I = dominant white, i = recessive permitting expression of color; R = red. r = white, recessive to red. The proportions of the F_2 generation are 13 white to 3 red.

By this cross it can be seen also how one character may depend upon more than one factor for its expression. Often many factors are involved in the determining of a single character. These are known as multiple factors, and their presence greatly complicates the understanding of genetics in man.

F_1

	R	R
r	Rr pink	Rr pink
r	Rr pink	Rr pink

F_2

	R	r
R	RR red	rR pink
r	Rr pink	rr white

Fig. 122.—Checkerboards to represent the results when red and white four-o'clocks are crossed. R = red, r = white. Red is incompletely dominant, so that the color of the hybrids is pink.

Incomplete Dominance

In the garden four-o'clock, Mirabilis, red and white flowers when crossed give neither red nor white, but pink, an obviously hybrid condition. In the F_2 the ratio is 1 red, 2 pink, 1 white. This is a 3-1 ratio in which the heterozygous individuals can be distinguished from the homozygous ones. Neither red nor white is dominant, but an intermediate condition exists.

That the pinks are heterozygous can be determined by crossing the F_2 individuals with mates of the same kind. The reds crossed together will give red, the whites give white, and the pinks give 1 red, 2 pink and 1 white; thus repeating the F_2 ratio.

This type of incomplete dominance explains why the blue fowl, known as the Andalusian, cannot be made to breed true. When black is crossed to splashed white, blue fowl result.

When blues are crossed together, however, 1 black, 2 blue, and 1 splashed white will appear. Such ratios are said to be unfixable.

THE CHROMOSOMES IN HEREDITY

The studies on the chromosomes and their behavior during reduction have cleared up the problems of inheritance. It is now recognized that hereditary factors are located in *genes,* which are carried on the chromosomes, and these genes occur in pairs just as the chromosomes occur in pairs.

The two chromosomes which unite in synapsis are not a haphazard choice. Each chromosome in a female gamete has a mate in a male gamete of the same species. The chromosomes of such a pair are *homologous.* The genes occupying identical positions on the chromosomes of a homologous pair are alleles. Any individual having a factor derived from one parent has its allele derived from the other parent.

Where more than one pair of chromosomes is involved there will be a random assortment of the factors on the separate chromosome pairs, since there is nothing to determine during the reduction division whether a tetrad will turn one end or another toward a given pole. Fig. 123 shows random assortment with four pairs of chromosomes, illustrating the eight possible combinations. The complexities of heredity are multiplied with the increase in chromosome number as, for instance, in man where there are twenty-four pairs.

The history of pairs of alleles showing random distribution due to segregation is a demonstration of the laws of genetics. A factor located in a gene on the chromosome is expressed in an individual as some somatic character. Thus a gene which is expressed as a black color is called a factor for black. It will have an allele on the homologous gene which may be a factor for black, or may be a factor for white.

So far as is known the gene is some specific chemical arrangement of molecules in the chromomere, maintaining a position relative to the other genes on the same chromosome, and very stable under normal conditions. Its effect on the somatic tissues is probably very similar to the action of enzymes or hormones.

Types of Chromosomes

There are two types of chromosomes: the *autosomes* which occur in pairs, and the *sex chromosomes,* more often called *X-chromosomes,* which are paired in one sex only. The usual condition is that in which the X-chromosome is paired in the female (XX) and unpaired in the male (XY). The *Y-chromosome* is sometimes absent, but when present it may exist as a

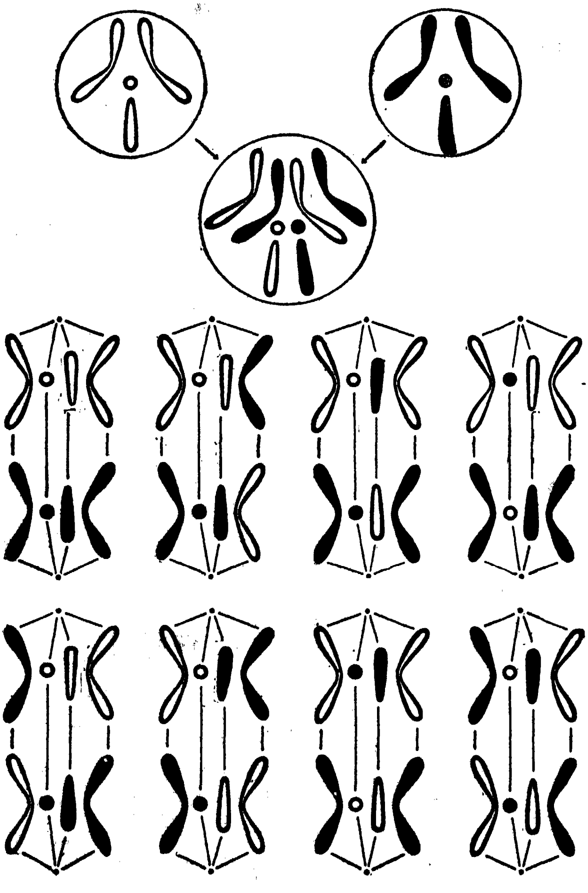


Fig. 123.—Diagram to illustrate the random distribution of chromosomes in the female *Drosophila melanogaster* which has four pairs of chromosomes. Upper left, chromosomes contributed by the female parent: upper right, those contributed by the male parent to the zygote containing the diploid number of chromosomes. Below are shown the eight different types of distribution which occur during the formation of gametes by an individual with such a combination of chromosomes. (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

single chromosome or as a group of small chromatic elements. Often the Y-chromosome has a hook on the end or some other distinguishing mark. For the most part it is inactive, although in some fishes a functional Y has been demonstrated.

In birds and in moths the paired condition of the X-chromosome is reversed, the male having the XX condition, the female the XY. The sex having the Y-chromosome is known as the *heterogametic* sex.

Sex Determination

The history of the chromosomes in *Drosophila melanogaster* demonstrates the behavior of the X-chromosomes in relation to the autosomes. This species has three pairs of autosomes, two long, curved pairs (chromosomes II and III) and one small dot-like pair (chromosome IV). The sex chromosome is short and rod-shaped and is designated chromosome I. In the male the Y-chromosome has a hook on one end which makes it plainly discernible in cytologic preparations.

During the process of reduction in the male, as shown in Fig. 125, the X- and Y-chromosomes will separate so that one-half of the sperm will receive the X and one-half the Y. In the female, since the X is paired, every egg will receive one X and all eggs will be alike. If an egg be fertilized by a sperm carrying the X-chromosome, the zygote will have the XX condition and must develop into a female. If the egg be fertilized by the sperm carrying the Y-chromosome, however, the zygote will have the XY condition and will develop into a male.

Thus the sex of any normal individual will be determined at the time of fertilization, and even in cases where embryos appear to pass through indifferent stages in which the sex is not discernible, the direction of its development has been laid down in the organization of the fertilized egg.

Sex of Twins.—There are two types of twins: fraternal twins, which develop from two separate eggs, and identical twins, which develop from a single egg. Fraternal twins may be of the same sex or of different sexes, but identical twins must be of the same sex since the sex is determined at the time the egg is fertilized, and no matter how early or late in development the division takes place, the sex will be the same.

Fraternal twins may resemble each other as much as ordinary brothers and sisters, but identical twins may often be taken for each other. They will have the same color of hair and eyes, the same texture of hair, and the same complexion. They will be of the same blood group. These are a few of the factors used in determining whether twins are identical or not.

Variations in Sex

Hermaphrodites.—In the majority of the plants and in many of the lower invertebrates organs of both sexes occur in the same individual. Even under these circumstances, however, cross-fertilization is the rule. The earthworm is a good example. See page 485.

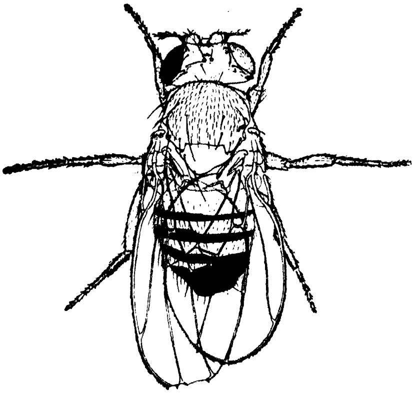


Fig. 124.—A bilateral gynandromorph in *Drosophila melanogaster* with female characters on the left side and male characters on the right. (Photograph by C. B. Bridges. From White: Principles of Genetics. The C. V. Mosby Co.)

Gynandromorphs.—Animals having male organs on one side of the body and female organs on the other are known as bilateral gynandromorphs. Externally such individuals have a mosaic appearance, since the male side may show recessive somatic characters and the female side dominant or hybrid characters.

The condition is caused by an abnormal division in the cleavage of a female zygote (XX). In one cell resulting from the first cleavage of the egg, one of the X-chromosomes is eliminated, while the other cell retains the two. In all resulting divisions one-half of the cells will have the XX condition and one-half the XY, or male condition. If the X-chromosome in these cells happens to be the one carrying recessive alleles, that side of the animal will have a different somatic appearance from the other.

Mosaics may occur from other types of abnormal cleavage as in the patroclinic gynandromorphs in ants where the head has one set of characters and the body another. The bilateral type is by far the most common, however. It occurs sporadically in birds, but the commonest types are found among the insects. Fig. 124 shows a bilateral gynandromorph in *Drosophila melanogaster*.

Intersexes.—Normally the differentiation between the male and female individuals in any species is a sharp one. Female individuals having a tendency toward maleness and male individuals with a tendency toward femaleness have long been recognized. Hereditary conditions of this type have been established by Bridges in *Drosophila melanogaster* and by Goldschmidt in the Gypsy moth, *Lymantria dispar.* Bridges explained this condition by the abnormal distribution of chromosomes during the reduction division, resulting in abnormal gametes. The chromosomes concerned may be the X-chromosome or the small dotlike chromosome (chromosome IV). The process is known as nondisjunction. A pair of homologous chromosomes fail to separate during the reduction process so that an extra chromosome is found in one gamete and a chromosome is missing from the other.

According to Bridges, the sex chromosomes do not carry factors for maleness or femaleness, but they establish a balance between themselves and the autosomes. Normally the balance 2A:2X produces a female and 2A:X-Y, a male. Any disturbance in the balance as 3A:2X or 3A:XY causes an intersex. If the fourth chromosome also drops out in these strains, there is a change in the intersex toward maleness. If an extra fourth chromosome is present, the tendency is toward femaleness.

This is known as the *balance theory* of sex determination. Sex is not determined by the distribution of the X- and Y-chromosomes alone, but also by the balance established between a group of autosomes and the sex chromosomes.

In *Lymantria dispar* Goldschmidt established an intersexual strain by a racial cross between a European and Japanese variety. This strain showed not only all grades of intersexuals, but also a tendency to sex reversals. Goldschmidt infers from his results that there is a male-determining gene on the X-chromosome (the female is the heterogametic sex in moths) and a female-determining gene on the Y-chromosome. If the X-chromosome of one race is stronger than the one of the other race, racial crossings may establish intersexes. In Lymantria an intersexual with the genetic constitution XY will develop as a female up to a specific turning point in its development. At that point the development will depend upon whether the X-chromosome is from the Japanese or European race. Since the Japanese race in Lymantria has a stronger influence than the European, an XY female intersex with a Japanese X will tend to develop toward the male side and may show actual reversal in the male direction.

It is thus apparent that the sex balance may be upset either by the abnormal distribution of chromosomes or by racial crossings.

Sex Linkage

Factors which lie on the X-chromosome have a peculiar distribution because of the unpaired condition in one sex. Characters which are determined by such factors are not limited to one sex but are known as sex-linked characters because their distribution follows that of the X-chromosome.

If the male is the heterogametic sex as is the case in Drosophila and in man, the male can never be heterozygous for a sex-linked factor, and a recessive factor on his X-chromosome can never be concealed. It follows that a male can never inherit a sex-linked factor from his father, though a female may inherit from either parent. In the case of color blindness, which is due to a sex-linked recessive factor in man, the father may not transmit this factor to his son but may transmit it to a grandson through a heterozygous daughter. See checkerboards in Fig. 126.

A similar case occurs in the factor for the white eye in Drosophila shown in Figs. 127 and 128. In Fig. 128 the sex-linked recessive is present in the female, whereas the normal allele is in the male. In such a mating all daugthers will have red eyes and all sons white eyes. This is known as criss-cross inheritance. In the second generation, males and females of both types may produced.

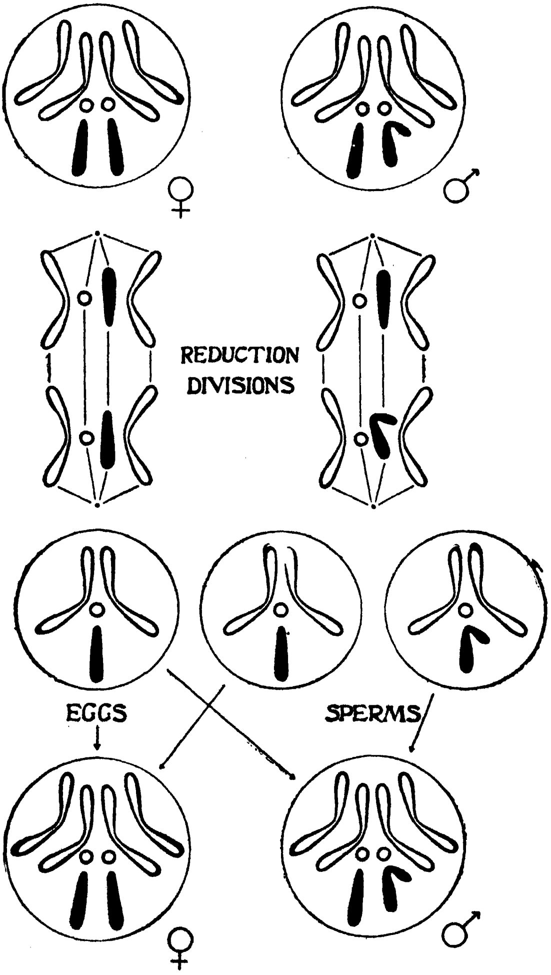


Fig. 125.—Diagram to show the distribution of the sex chromosomes during reduction in *Drosophila melanogaster*. The sex chromosomes are represented in solid black, and the Y-chromosome is hooked at the end. The arrows show the sex resulting from the fertilization of the eggs by the two kinds of sperms. (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

Inheritance in Man

In applying the knowledge of genetics to man, one is met with immediate obstacles, for man has twenty-three pairs of autosomes plus an X-Y pair, and the possibilities involved in independent assortment are too numerous to follow. The chances for any one autosome from a paternal grandparent reappearing in a grandson is estimated as $1:2^{23}$, or one chance in 8,388,608. The grandson has one chance in six, however, of receiving the paternal grandparent's X-chromosome. Sex-linked characters are more easily followed, therefore, than autosomal ones, and several such characters have been established as unit factors in man.

	N	N
n	Nn Normal female	Nn Normal female
	N Normal male	N Normal male

Characters:
2 normal females
(heterozygous)
2 normal males

	N	n
N	NN Normal female	Nn Normal female
	N Normal male	n Color blind male

Characters:
2 normal females
(one heterozygous)
1 normal male
1 color-blind male

Fig. 126.—Checkerboards to illustrate the F_1 and F_2 results in a sex-linked cross. The factors are carried on the X-chromosome, and are, therefore, single in the male. N = normal, n = color blindness.

Sex-Linked Inheritance.—The most common of the sex-linked characters is color blindness of the red-green type which is due to a partial failure of the cones on the retina of the eye to differentiate between certain colors. There are two types. In one the reds appear darker than the greens, and in the other, the greens appear darker than the reds. Since both types may appear in the same family, it is not due to a single recessive gene. However, the distribution follows that of the X-chromosome and is easily followed.

If the character appears in the grandfather and his wife is normal, none of their children will be color blind, but their

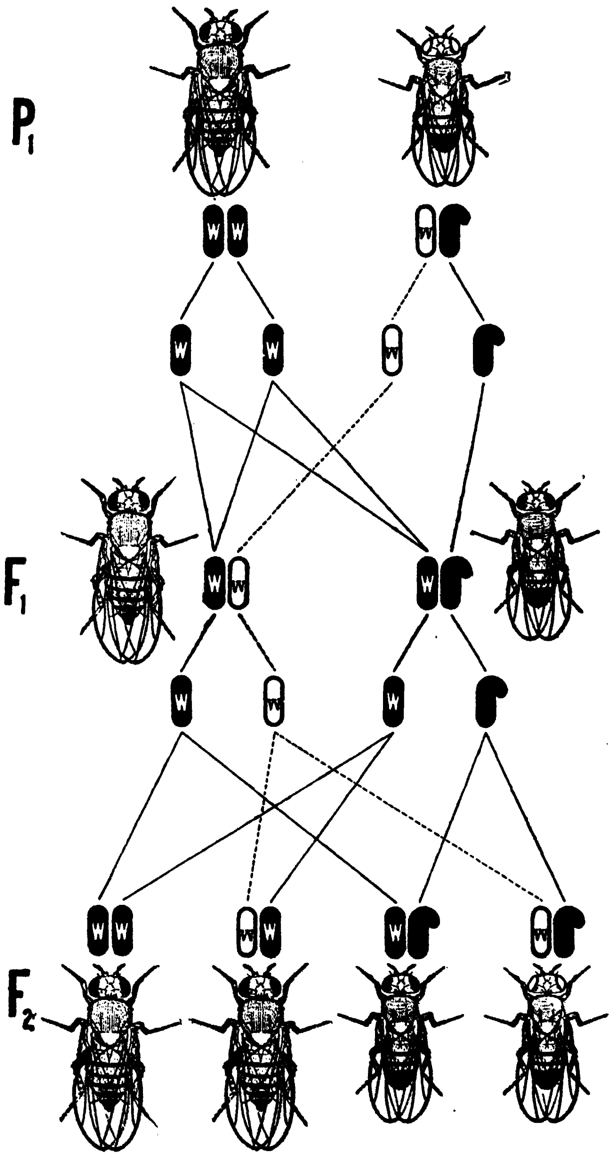


Fig. 127.—Inheritance of white eye color in Drosophila. The history of the white eye is similar to that of color blindness. Red-eyed female mated to white-eyed male. Solid lines indicate the history of chromosomes of P_1 female and Y-chromosome; dotted lines, history of X-chromosome of P_1 male. (Adapted from Morgan.) (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

daughters may transmit the character to a grandson. Color-blind women will occur only when a color-blind man marries a woman who is a carrier.

Hemophilia is another well-known case of sex-linked inheritance. This is a disease in which the clotting power of the

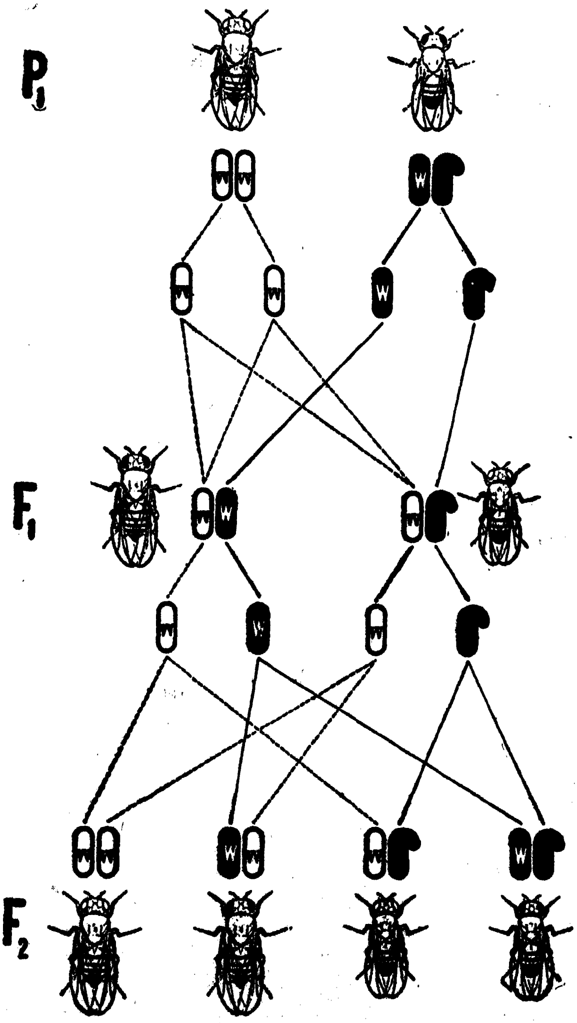


Fig. 128.—Inheritance of white-eye color in Drosophila. White-eyed female mated with red-eyed male. Dotted lines indicate history of chromosomes of P_1 female; solid lines, of the P_1 male. (Adapted from Morgan.) (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

blood is greatly reduced in man, and this type of distribution explains why so many of the male descendants of Queen Victoria have died from minor accidents. Life has become increasingly hazardous for persons with hemophilia. Only one of Victoria's four sons was afflicted and he lived to marry and have children. Lord Trematon, son of his daughter, Alice, lived in a more dangerous age and died in a motor accident, as did also the two late princes of Spain.

Autosomal Inheritance.—Many characters in man which act as unit factors in inheritance are known and their distribution understood. Human matings are not subject to experiment or control, and the numbers of offspring in any one family are often too few to draw definite conclusions. For this reason the statistical method of approach has proved the most satisfactory, for, by applying the law of averages to a sufficiently large volume of data, fairly accurate deductions and fairly reliable forecasts can be made. It is known, for instance, that a heterozygous dominant can be expected to appear in about one-half of the offspring in each generation, and that those individuals who do not show the trait cannot transmit it. Recessives, on the other hand, will skip generations, and, where outbreeding is normally practiced, may remain hidden for several generations. A recessive, to make its appearance, must enter from both sides of the family.

A large proportion of the known hereditary factors in man are abnormalities. This is natural since the abnormal makes a greater impression than the normal. The characters in man which are of the widest social significance, however, are the normal characters. Certain of these are racial such as hair color and form, skeletal dimensions, thickness of bone, and voice placement. Others are of universal distribution such as intelligence, personality, and susceptibility to disease.

Types of inheritance in man may be listed as *single factor inheritance, multiple factor inheritance,* and *factors influenced* by the *environment.* Practically nothing is known in man of linked inheritance and crossing over which must account for many of the discrepancies in the distribution of factors through families. Such knowledge is impossible without experiment and control.

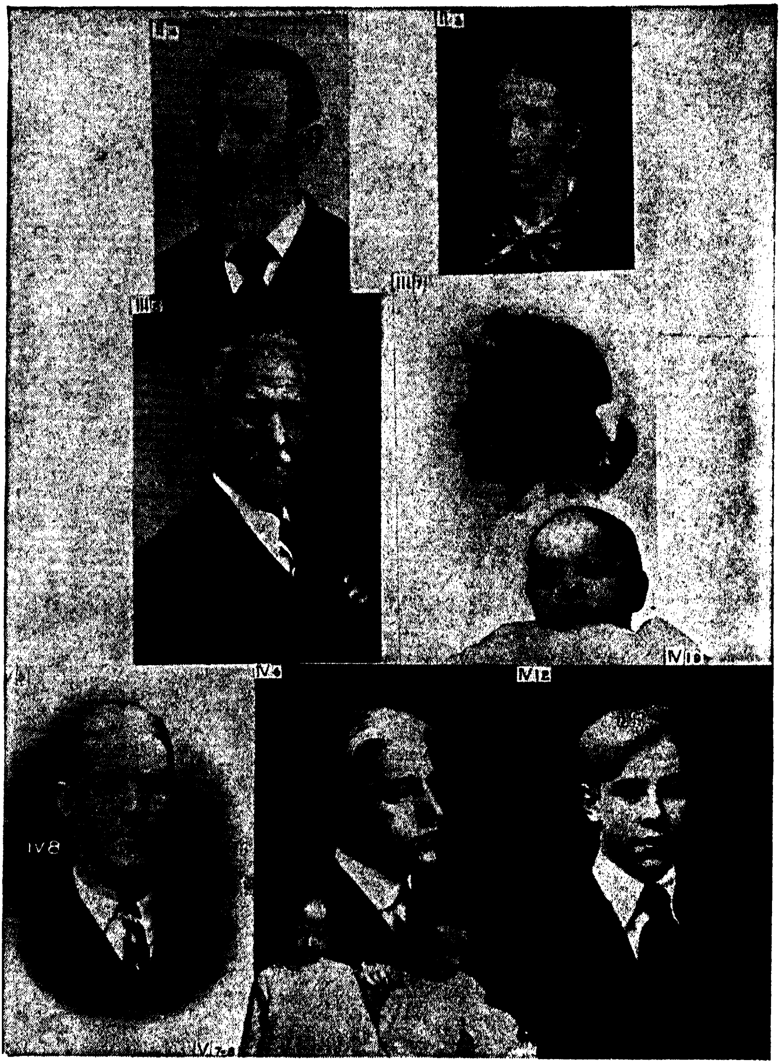


Fig. 129.—Four generations of family whose pedigree is shown in Fig. 130. Individuals are numbered according to their position on the pedigree. *III-5* and *III-7* are brother and sister. Although the hair of *III-5* had turned completely white when the picture was taken, white spotting shows clearly on the forehead. Note the same forehead marking in *IV-19* and the white areas in the eyebrows of *LV-8* and *LV-12*. (From White: Principles of Genetics. The C. V. Mosby Co.)

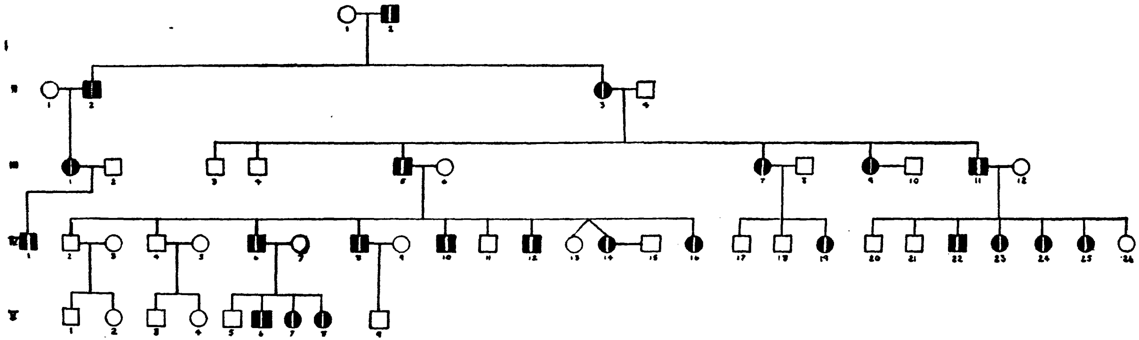


Fig. 130.—Pedigree showing the dominant inheritance of white spotting in man. Areas of the skin on the forehead, arms, legs, and body, as well as the hair and eyebrows are spotted. Note that the individuals not affected do not transmit the character. (From White: Principles of Genetics. The C. V. Mosby Co.)

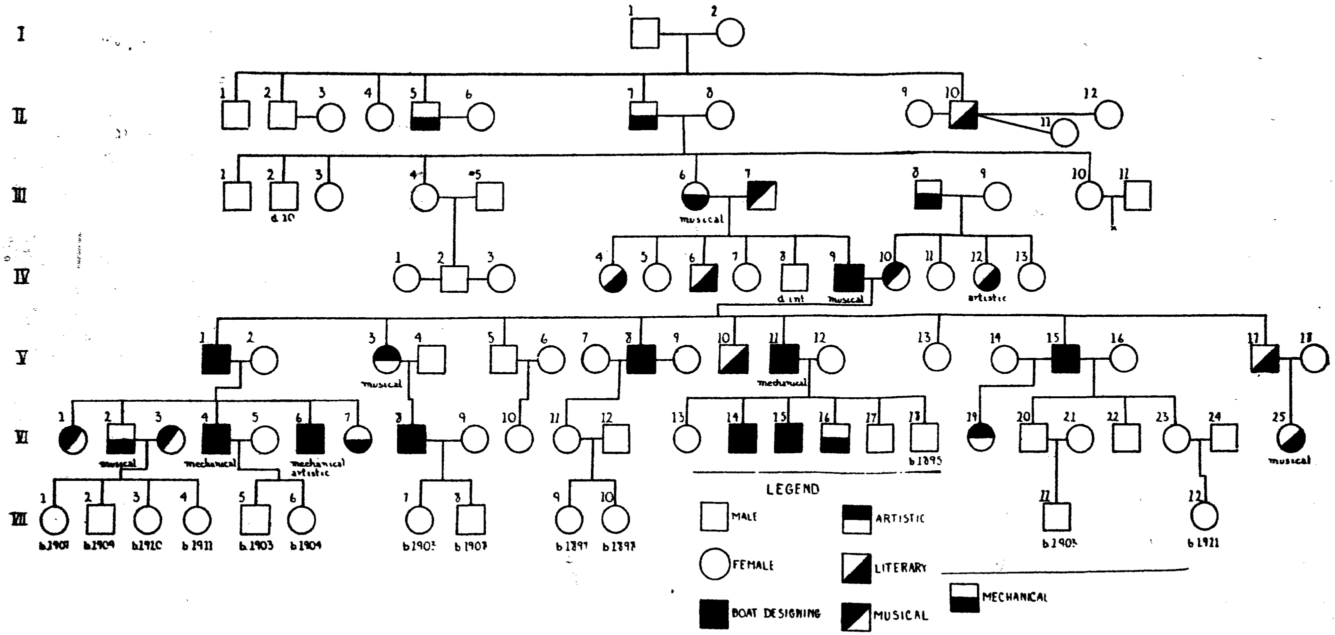


Fig. 131.—A famous American family of geniuses, displaying mechanical skill and artistic temperament. The boat designers of this family have been the designers of the swiftest sailing boats in the world. (Courtesy of the Eugenics Record Office.)

Single Factor Inheritance.—There is a dominant factor, C in man, which is necessary for the production of any pigment. Its recessive allele, c, accounts for albinos. In albinos the eyes are pink since in the absence of all pigment in the iris, the hemoglobin of the blood capillaries shows through. The hair of albinos is white and the skin very fair. Albinos are extremely sensitive to light because pigment in any form is protective against light. The factor, C, apparently has universal distribution in animals and plants, since albinos may appear in any species.

When C is present, color in the iris depends upon a factor, B, which permits distribution of pigment in two layers: one purple-black layer behind the iris and one brown layer in front of the iris. The recessive, b, accounts for absence of pigment in front of the iris, causing blue or gray eyes. The color is caused by the refraction of light rays from the pigment layer back of the iris.

The amount of brown pigment is due to multiple factors, as is the color of the skin.

A dominant factor, S, accounts for the spotting of the skin. On white skin this is not apparent except when the skin has been sunburned, for the white areas will not burn or tan. The spotting is usually accompanied by a streak or "blaze" in the hair. The photographs in Fig. 129 show four generations of a family with this spotting factor, and the pedigree in Fig. 130 shows five generations of the same family. This chart shows plainly the distribution of a dominant trait. Those individuals who do not show the trait do not transmit it, and those who do transmit it to about one-half of their children.

The spotting in this family is especially interesting because the white area extends down over the forehead, especially noticeable in the infant *IV-19*. It often affects one-half of the eyebrows as can be seen in the photographs of *IV-8, 6,* and *12.* There are scattered spots on the arms and legs, and in several individuals there has been a semicircular band on either side of the body under the arms.

CHAPTER XV

SOME PROBLEMS OF THE PAST

The Pre-Greek Period

When one considers the antiquity of man, science of all kinds is of fairly recent origin, but early man, though unscientific, was still curious, and the records which he left on the walls of caves leave no doubt of his interest in the world of nature. Babylonian inscriptions and Egyptian relics show the use of surgical operations, the domestication of animals and the cultivations of plants in the earliest periods of history. Moreover, recent French explorations in Mesopotamia have unearthed evidence that horses were bred for pedigreed lines over five thousand years ago. Fig. 133 is a reproduction of the seal unearthed by the French explorer, de Mecquenem, in Elam. Note that the horse heads are arranged in horizontal rows and that three types of mane (erect, pendant, and maneless), and three types of profile (convex, straight, and concave) are shown. The profile types are found in horses today, and it seems probable that this seal represents the oldest horse pedigree in existence. This evidence leaves little doubt that man had made scientific advances fifty centuries ago.

The Greek Period

In spite of his efforts, however, the mind of early man was hampered by fears, superstitions and taboos that were passed on from generation to generation by word of mouth, and the absence of tools and magnifying lenses delayed the necessary observations for scientific advance.

The accomplishments of the Greeks are the more remarkable, therefore, when we consider that they worked without lenses and under the bizarre inhibitions of an ancient mythology, whereby anything might happen in nature at any time through the intervention of the gods.

Aristotle (384-322 B.C.).—There is a tendency to overrate the achievements of the early scientists because of the long period, not many centuries past, when Greek learning was looked upon as the last word in culture. There is always a tendency, too, to eulogize a few outstanding names when many have contributed to the ideas they have given voice to. Notwithstanding these facts, the name of Aristotle must always bring some thrills to the heart of the naturalist. For here was a man, politician, philosopher, and teacher, who took time to observe the little things in life—to watch the chick developing in an egg, and the cabbage worm emerging from its cocoon. In his curiosity he drew conclusions on natural phenomena that were far in advance of his time, and suggested the possibility of a series of animals from polyp to man which, in essence, is in accord with modern ideas of relationships. The prevailing idea that earth, air, fire, and water were the units of Nature probably accounts for the errors which seem obvious today. A knowledge of gases would have explained many of the phenomena which mystified him, and the

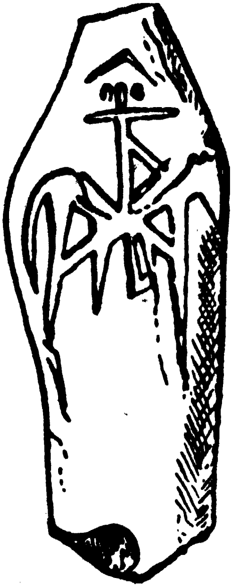


Fig. 182.—The horseman of Susa (2800 B.C.). After de Mecquenem and V. Scheil. Figure engraved on a fragment of bone discovered in Elam to the East of Ur. The oldest image of the horse in the history of human culture, proving that the horse was domesticated five thousand years ago. (Reproduced by permission from Amschler: Die Ältesten Funde des Hauspferdes.)

possession of a lens would have enlarged his world, but these discoveries were delayed for many centuries by the slavish adherence to the theories of the ancients.

His rhetoric and ethics are perhaps better known today, yet, even so, Aristotle stands out as the champion of direct observation in Nature and the founder of the science of Zoology. His observations would fill many volumes had they been left to posterity, but much that we know of his work is from poor translations and awkward quotations by later less gifted men. Especially is this true of his observations on plants. These we know chiefly through his pupil, Theophrastus.

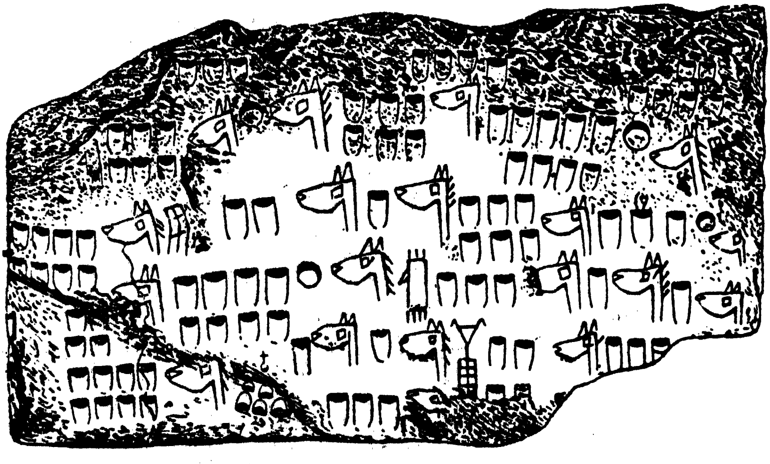


Fig. 133.—Pedigree of horses, c. 4000 B.C. After de Mecquenem and V. Scheil. Engraved seal from an excavation in Elam to the East of Ur in Chaldea. Believed to be a record of animal breeding. Note the three types of profile: straight, concave, and convex; and the three mane types: upright, pendant, and maneless. The heads are arranged in four horizontal rows with repeated symbols. The symbols are a matter of conjecture, but the heads appear to represent some sort of classification. The three profile types are found on horses today. (Reproduced by permission from Amschler: Die Ältesten Funde des Hauspferdes.)

Theophrastus (372-288 B.C.).—Theophrastus was a much less thorough observer than his instructor, but he had the gardens of the Lyceum at his disposal and many foreign plants sent to him by devoted pupils traveling in other lands. He wrote two exhaustive treatises—the *Historia Plantarum* and *de Causis Plantarum.* Although containing few original observations, these did contain discussions of seed germination

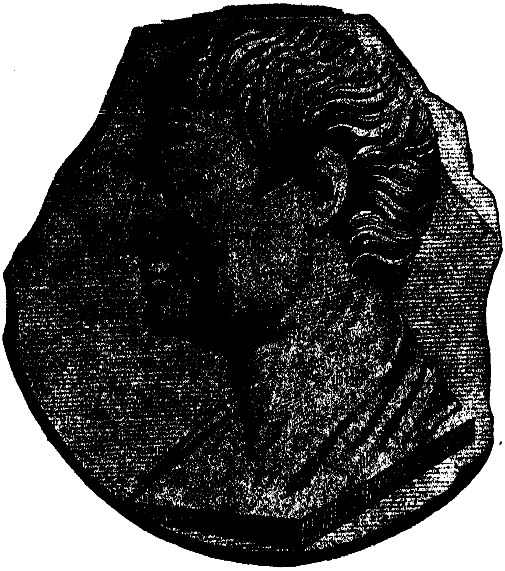


Fig. 134.—Aristotle, 384-322 B.C. The pioneer among naturalists. From a bas-relief found in the collection of Fulvius Ursinus. (Visconti, Iconographie grecque.) (Reproduced from Locy: The Growth of Biology. Published by Henry Holt and Co.)

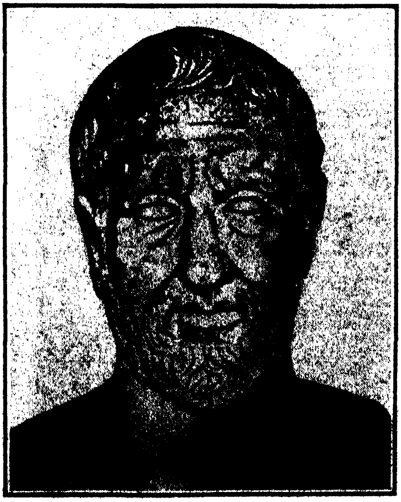


Fig. 135.—Theophrastus, 372-288 B.C., the pioneer botanist. From Villa Albani, probably A.D. second century. Studies in the History and Method of Science, 1921. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

and plant propagation. Moreover, he recognized plant associations and introduced a primitive classification. He stands, therefore, easily the founder of the science of botany.

The Alexandrian Period

From Greece, learning passed to Egypt where the Alexandrian Museum became the center of science. Natural science was not greatly stressed and the period would have had no interest for the naturalists, save for the Alexandrian school of medicine established there. This school under two able physicians, Herophilus (ca. 335-280 B.C.) and Erasistratus (ca. 300-260 B.C.), attained some prominence. It is especially noted for the extension of dissection to the human body, a practice which was later proscribed for centuries. Had the physicians of the Middle Ages had access to the descriptions by these two men, medicine would not have been so late in acquiring accuracy, but Alexandrian teachings were discounted in the Roman period which followed, and it was a Roman physician, Galen, who established the science which became the authority for the Middle Ages.

The Roman Period

Roman supremacy suppressed cultural development. Military interests supplanted the intellectual and with the establishment of the Christian religion, human dissection was proscribed. This ban on scientific advance held sway for fourteen centuries, greatly hampering the work of the medical schools and delaying all work of importance.

Pliny (A.D. 23-79).—Pliny, the elder, in thirty-six books on natural history reviews the knowledge of this period in all phases of science. The books are filled with fables, superstitions, and magical cures, but he drew largely on Greek science for data on natural history, and so kept alive the teachings of Aristotle in a greatly garbled and misquoted account.

The only real scientific work of the Roman period was contributed by two Greeks who lived in Rome, Dioscorides and Galen.

Dioscorides (ca. A.D. 40-90).—Pedanois Dioscorides was a botanist of note. Unfortunately, he confined his descriptions to plants of value in medicine and so established a medical botany of limited value. He was more accurate than Theophrastus and his work was recognized as an authority in the Middle Ages so that his limitations impeded advance in botany.

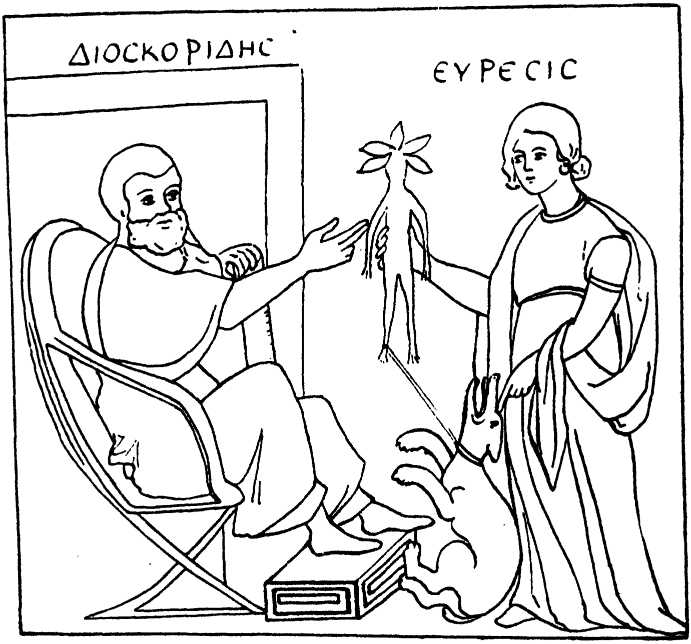


Fig. 136.—Dioscorides, A.D. 40-90, medical botanist. Restored from the Juliana Anecia MS., Fol. 4, verso, about 512 A.D., Studies in the History and Method of Science. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

Galen (A.D. 131-200).—Galen was of Greek lineage and was born in Asia Minor. He later moved to Rome and became the most successful physician since the Alexandrian School. The wonder is that he benefited so little from the human dissections of Herophilus and Erasistratus, since the practice was forbidden to him. So firmly did he believe in direct observation, however, that, although familiar with the former works, he discarded them wherever they failed to agree with his observations on elephants, barbary apes, and swine. His *Anatomical Administrations* later became the authority for eleven

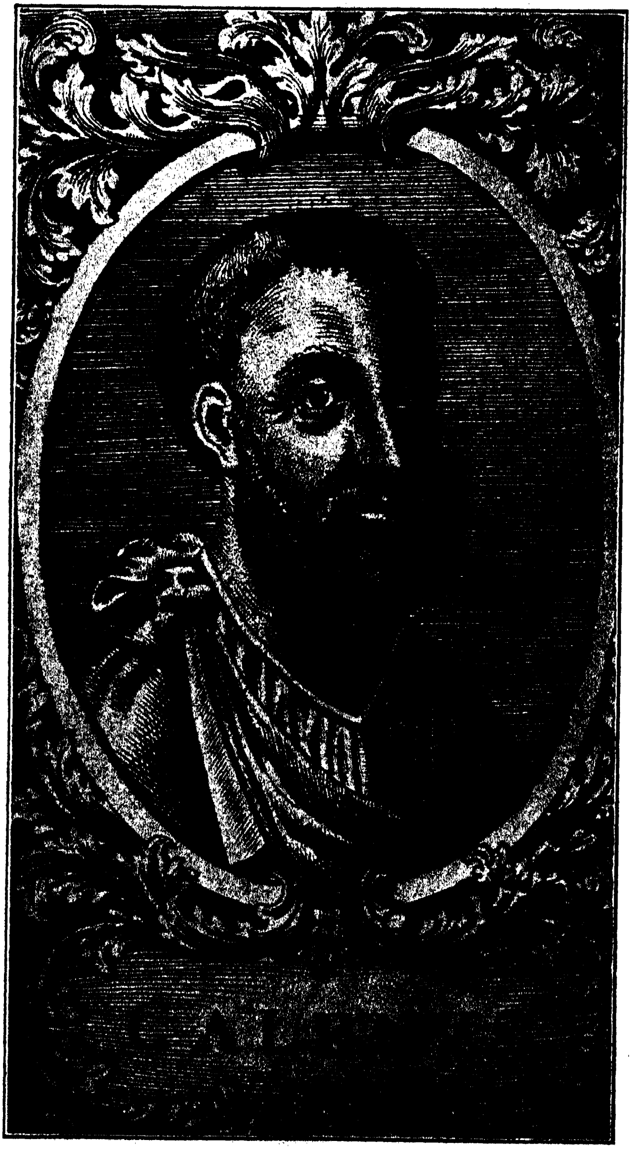


Fig. 187.—Galen, A.D. 131-200, medical anatomist. Acta medicorum Berolinensium, Vol. 5, 1719. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

centuries, a practice he would himself have descried, although a little more reliance by him on previous authority would have greatly hastened scientific advances.

False as many of his statements are, he was the first really great anatomist. He used both observation and experiment, and was the first to describe accurately the respiratory process and to establish the functional and structural connection between the central nervous system and the muscles.

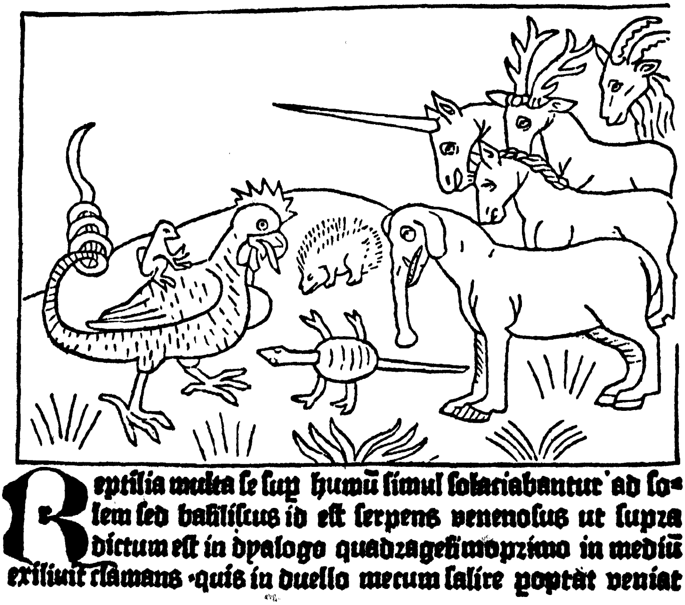
The Medieval Period

A series of invasions by the barbarians subjugated the Western Empire and obscured its culture. Public schools were no more and a lethargy settled over the people of Europe, dulling the urge for learning. Learning was kept alive through the monasteries, but it was a stereotyped sort of learning, aiming to pass on a body of acquired knowledge without attempting to expand its bounds. Reliance on authority was absolute. Aris-

Fig. 138.—Avicenna, A.D. 980-1037, Arabian physician. Acta medicorum Berolinensium, Vol. 6, 1720. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

totle's philosophy, even though in badly transcribed Latin, and the medicine of Galen and Hippocrates were recited verbatim, and only by disputation could the student exercise his wits.

Thus for a thousand years no natural science of note developed, although a fantastic interest in Nature was kept alive by frequent encyclopedic works of popular appeal. Filled with fables, superstitions, and garbled information though they were, these works reached a wide audience. The earliest was the *Physiologus* of the third or fourth century. Like the others, it is of doubtful origin, but it sheds an interesting light on the groping mind of this elusive period.



Reptilia multa ſe ſup humū ſimul ſolaciabantur ad ſo-
lem ſed baſiliſcus id eſt ſerpens venenoſus ut ſupra
dictum eſt in dyalogo quadrageſimoprimo in mediū
exiliuit clamans ·quis in duello mecum ſalire poptàt veniat

Fig. 139.—Animal pictures from the Diologus Creaturarum. 1480. Pierpont Morgan Library. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

The twelfth century saw an awakened interest. Through frequent Crusades and through the opening of trade routes to the Orient, the European's geographic horizons were widened, and he was introduced to a new and exotic culture. A few of the more learned came in contact with the Arabian naturalists at the University of Bagdad. There, searchers after truth had been uninhibited, for there was no ban on pagan literature, and a more complete and more accurate account of Aristotle's work was freely used. Here in an atmosphere of life elixirs and love potions where alchemists still searched for the Philosopher's Stone that would turn baser metals into gold—here in the midst of superstition and magic Avicenna wrote his Canons of Medicine. Galen was the authority for the canons but much original work was introduced and Aristotle was quoted freely. Avicenna's explanation of certain geologic phenomena anticipated later theories by several centuries.

Avicenna's medicine was introduced into Europe through one Adelard of Bath (ca. 1130) and became a recognized guide in European universities until the seventeenth century. The *Knowledge Books* of the thirteenth century introduced Aristotle's Natural History, and a revival of interest spread among the people. The fifteenth century saw the introduction of printing with movable type with the consequent wide dissemination of knowledge, the awakening of curiosity, and the opening of a new era in science.

The Revival in Botany

The revival came earlier in botany than in zoology because of the popular interest already existing in the manuscripts depicting the medical virtues of plants. As soon as printing began, many of these manuscripts were put into print and reached a wide audience. The information contained in them may have dated back many centuries, so the date of printing gives no idea of their date of origin. It was through the art of illustration that the first approach to accuracy was made.

The first authentic wood cuts are found in Conrad's *Book of Nature* (Das Püch der Natur), first printed in German in 1475. Another popular herbal of the time was a small Latin treatise called *The Herbarium of Apuleius Platonicus,* first printed in 1484. The manuscript is believed to date back to the fifth century. The text and figures had been copied from manuscript to manuscript innumerable times before the first printing, with many resulting accuracies. The medical virtues of the plants are shown in the figures. If the herb was known as an antidote for the sting or bite of an animal, the animal was drawn into the figure, so that serpents and scorpions appear frequently in the cuts.

There were many of these herbals. They appeared in many editions in a very short time to satisfy the popular demand. The sixteenth century saw a decided step forward in the illustrations in Brunfels' *Herbarium vivae,* first published in 1530. The artist was Hans Weiditz. He drew the plants from nature, neither conventionalized nor mixed with superstitions. The pictures were far better than the text (Fig. 140).

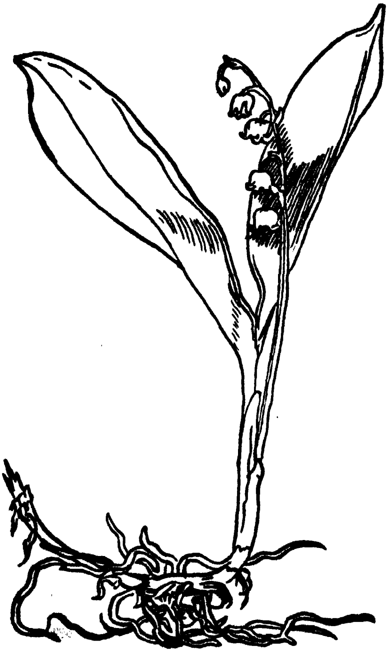


Fig. 140.—Lily of the Valley. From Brunfels, Herbarium vivae eicones, 1530. John Crerar Library. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

Herbals followed in swift succession in all countries, and by the seventeenth century, interest in botany had turned from the strictly utilitarian interest in the medical virtues of plants to a more philosophical interest in their relationships. This led to the various attempts at classification which culminated in the eighteenth century in the work of Linnaeus.

Carolus Linnaeus (1707-1777).—No name stands out more sharply in the emancipation of science than that of Linnaeus, whose clear-cut descriptions established a pattern for many taxonomists to come. He worked with animals as well as with plants but he was a better botanist than zoologist, for he recognized only two invertebrate groups, the Insecta and the Vermes. His general plan of classification was sound, however, and by establishing binomial nomenclature, he gave to the world an invaluable key for the coordinating of future discoveries.

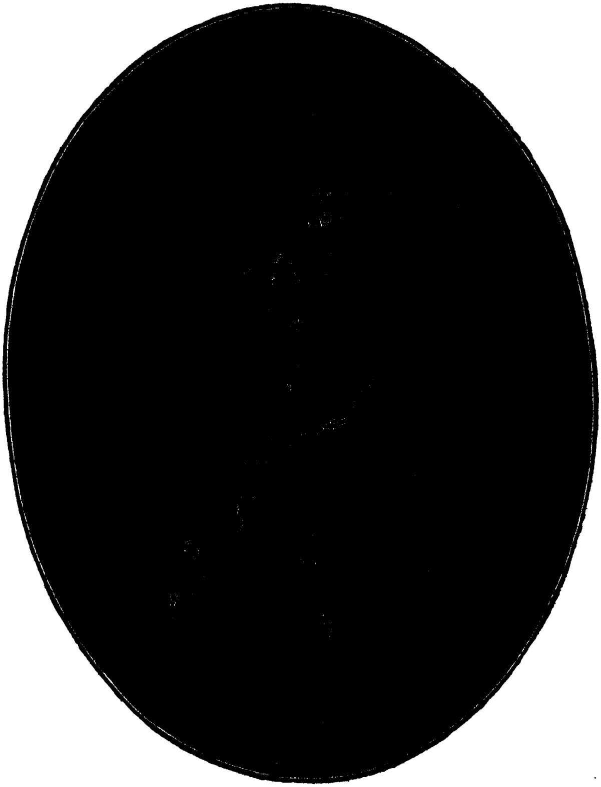


Fig. 141.—Linnaeus at sixty. (Reprinted by permission from Locy: Growth of Biology. Published by Henry Holt and Co.)

He was not the first taxonomist to present a natural system of classification. Ray (1628-1705) had already recognized the genus and species, and the binomial nomenclature was borrowed from Bauhin of the sixteenth century. Many attempts at classification had been made in fact, and yet to Linnaeus it remained to bring together into an orderly array the frag-

Fig. 142.—Andreas Vesalius, 1514-1564. Frontispiece, facsimile edition of 1728, Northwestern University Library. (Reproduced from Locy: Growth of Biology. Published by Henry Holt and Co.)

ments of chaos, and by designating each species by both a genus and a species name to pave the way for a new orderliness in nature.

Revival in Zoology

The revival of learning in zoology came first through the medical schools. The authority of Galen's anatomy had been unchallenged for so many centuries, that even with the introduction in the fifteenth century of legalized human dissections in some of the Italian medical schools, a general skepticism reigned. When the dissections differed from the descriptions by Galen, the instructors doubted their own eyes and passed the matter off as abnormalities.

Fig. 143.—William Harvey, 1578-1657. (From Garrison: History of Medicine. Published by W. B. Saunders Co.)

Andreas Vesalius (1514-1564).—It was a hundred years before this attitude was challenged. Vesalius was a dynamic young student from the start. He began his medical education in Brussels, but human dissections being still under the ban, he transferred to Padua where he eventually became a professor of surgery.

Even as a student he challenged Galen whenever his dissections failed to tally. He found his professors unsympathetic, but he persisted in pointing out the errors of Galen, and by demonstrating each point with clarity and precision, he succeeded in proving that direct observation was the only true criterion of knowledge—a point which Aristotle and Galen had demonstrated some fifteen hundred years earlier.

William Harvey (1578-1657).—While Galen combined observation with experiment, Vesalius was a pure anatomist, and it remained for Harvey to supplement his results by explaining the functions of organs. Many of his experiments had been previously performed by Galen, but by placing the emphasis on vital activities, Harvey became the founder of experimental physiology. He is best known for his discovery of the circulation of the blood.

The Age of the Microscope

The new era in science was well under way by the end of the sixteenth century. At about the middle of the century, two Dutchmen, father and son named Janssen, were grinding lenses for spectacles in Holland and starting something which was to open a new world to the scientist. For while Janssen's lenses were of the simplest type, and what is called his microscope was a mere tube with a lens at one end of it, the idea of magnification spread widely. By 1609 Galileo had invented his first telescope, and by the middle of the seventeenth century, biologists were becoming inventors to meet their ever increasing needs. Thus scientists have forced, step by step, the improvement in optical instruments, and much of the precision and delicacy of the modern instruments have been developed in response to their needs and to their persistence.

Robert Hooke.—In 1665 the Englishman, Robert Hooke, described the cell-like structures in cork. He used a very primitive type of instrument and to him the cells appeared much like the chambers of honeycomb. As these had previously been called cells, he applied the name "cell" to these new units of structure. It has since developed that the cell is anything but an empty space, but the name "cell" has been retained.

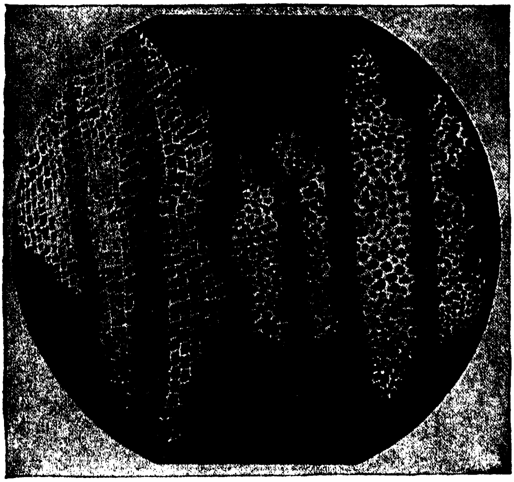


Fig. 144.—Robert Hooke's illustration of cork cells as he saw them under his microscope. Reduced facsimile reproduction from his Micrographia published in 1665. (Reprinted by permission from Textbook of General Botany by Holman and Robbins, published by John Wiley & Sons, Inc.)

Fig. 145.—Nehemiah Grew, 1641-1712. First published by Dr. Thornton, 1804. (Reprinted by permission from Locy: Growth of Biology. Published by Henry Holt and Co.)

Nehemiah Grew (1641-1712) observed vegetable anatomy in greater detail, and shares with **Marcello Malpighi** (1628-1694), the Spanish professor of anatomy, the honor of establishing tissues in plants. Malpighi perfected a lens with which he observed both animal and plant tissues, some of which still bear his name; i.e., the malpighian tubules of the insects. While he failed to see the significance of his observations, he is frequently referred to as the father of histology.

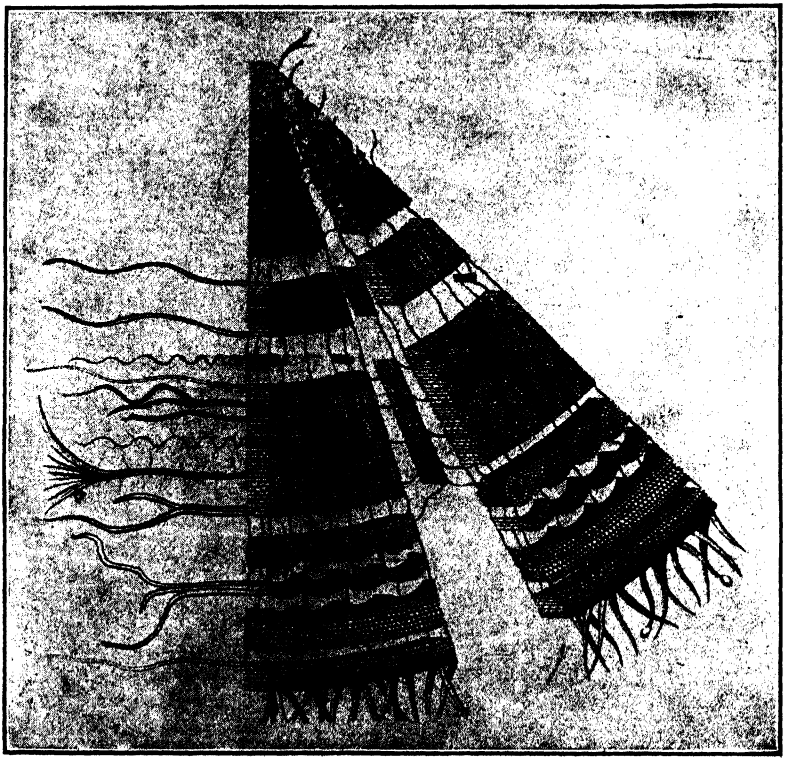


Fig. 146.—Microscopic structure of sumac stem as drawn by Nehemiah Grew in 1682. (Reduced.) (Reprinted by permission from Locy: Growth of Biology. Published by Henry Holt and Co.)

Antonj van Leeuwenhoek (1632-1723) invented a microscope which made possible a real advance in the knowledge of minute anatomy. He observed bacteria, blood corpuscles, spermatozoa, and many other hitherto unknown structures.

The study of the cell was delayed, however, over a hundred years, for during the eighteenth century the foundations laid by the seventeenth century microscopists were almost entirely neglected, and Malpighi and Grew were recognized as authorities in animal and plant structure.

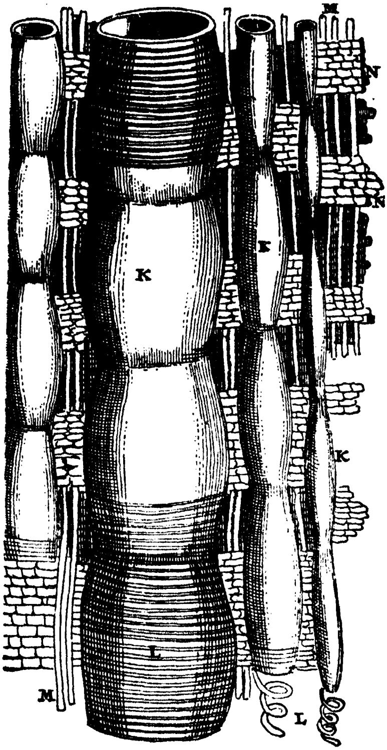


Fig. 147.—Microscopic structure of oak wood. (Malpighi, Anatome plantarum 1679.) (Reprinted by permission from Locy: Growth of Biology. Published by Henry Holt and Co.)

Schleiden and Schwann.—But with the promulgation of the cell theory in 1838-1839 by Matthias Jakob Schleiden (1804-1881) and Theodor Schwann (1810-1882), the great step was taken which laid the foundation for all modern biology—the conception of the cell as the unit of all life. Primitive as were the details of their theory, the idea was of universal significance and was almost immediately adopted by the scientific world. No theory, save the evolution theory, has had such far-reaching results, and without it, it is doubtful whether Darwin himself would have arrived at his conclusions.

It was thirty years, however, before the improvement in microscopic technique was sufficiently great to allow the beginning of those researches on fertilization and egg cleavage which were to prove so essential to the modern understanding of the cell. It was through embryology, therefore, and not through histology that the science of cytology was born.

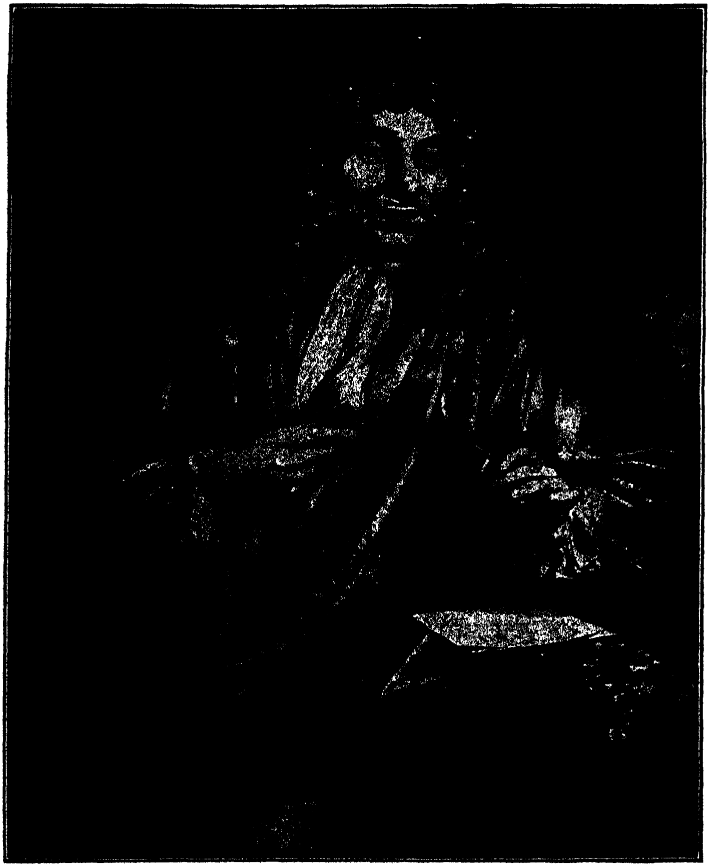


Fig. 148.—Antonj van Leeuwenhoek, 1632-1723. (From a painting by Veekolje, done in 1685.) (Reprinted by permission from Locy: Growth of Biology. Published by Henry Holt and Co.)

Protoplasm was first described by **Felix Dujardin** (1801-1860) in the one-celled organisms as a homogeneous mass which

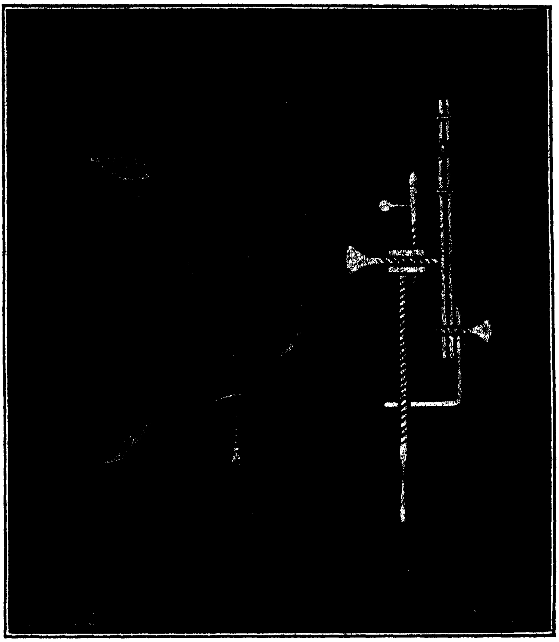


Fig. 149.—Leeuwenhoek's microscope, natural size. *1*, Rear view showing needle point on which objects are fastened. When viewing organisms in water, the needle is reversed and the organisms are viewed in a hanging drop of water. Note the minute opening where lens is inserted. *2* and *3*, Details of adjustment apparatus removed; *4*, side view of microscope; *l*, lens; *s*, adjustment screw. The lens is held close to the eye. (Reproduced from Dobell: Leeuwenhoek and His Little Animals. Published by Harcourt, Brace and Company.)

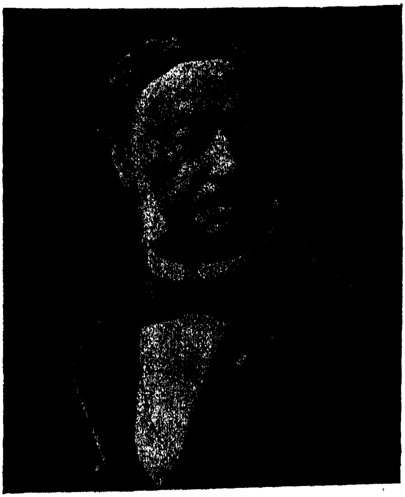


Fig. 150.—Theodor Schwann, 1810-1882. (Reprinted by permission from Garrison: History of Medicine. Published by W. B. Saunders Co.)

he called "sarcode." This name was used henceforth in referring to the substance of which animals were made, until in 1846 **Hugo von Mohl** (1805-1872) named the substance "protoplasm," which name has since been in general use.

Fig. 151.—Matthias Jakob Schleiden, 1804-1881. (Reprinted by permission from Locy: Growth of Biology. Published by Henry Holt and Co.)

Max Schultze (1825-1874) added the final touch by declaring that the protoplasm is the cell, and established the similarity of the living substance in animals and plants. Thomas Henry Huxley (1825-1895), the ardent champion of Darwinism, gave to protoplasm its classic definition—"the physical basis of life."

It is strange, considering the pioneer work of Dujardin, Schultze, and others, on living cells, that cytology should have been so long dominated by studies on fixed and stained objects, but the interest in this phase of the subject was stimulated by the discovery of indirect cell division (karyokinesis), more recently called *mitosis,* by Flemming. The dangers accompanying generalizations based on fixed material were recognized long before the study of living cells was again definitely resumed, but without the detailed work on the spindles and chromosomes, the brilliant work of the twentieth century, confirming each step made by the geneticist with cytologic phenomena, would have been impossible. While there are instances where the experimental evidence has not yet been confirmed by definite cytologic results, there is no case in which there is any real contradiction between the two, and the chromosomes have come to be considered almost exclusively as the visible expression of genetic results.

Parallel with these researches there have been since 1900 many experiments on living cells, especially upon developing eggs, with the result that today the entire conception of cell structure has undergone a fundamental change.

CHAPTER XVI

SOME PROBLEMS OF THE NINETEENTH CENTURY

The nineteenth century saw the gathering together of great masses of unrelated facts accumulated over a wide area of investigation, to make the coherent unit which is the biology of today. The stimulus which made this coherence possible was the natural selection theory which Charles Darwin published in 1859.

It must be understood at the outset that between the facts of development and the theories of evolution there is a great chasm. The facts are accumulated data and as facts they are incontrovertible. It is the interpretation of the facts which is subject to change and criticism, because a theory is some one's opinion of the method by which development came about, and this method is still shrouded in mystery.

But, though never explained, the idea of organic evolution as a basic principle in the organic world is accepted by all representative biologists today as a logical working hypothesis, because this idea best explains the facts which have been accumulated. Without it they stand as isolated, unrelated data; with it they form a coherent whole.

The Atomic Theory is such an hypothesis without which the known phenomena of the physical world would be beyond understanding. Today the physicist speaks with assurance of activities within the atom, and even, with the aid of the cyclotron, can split atoms and redistribute electrons according to plan.

Democritus (470 B.C.) spoke of the infinite space in which move an infinite number of atoms, so small that their size cannot be diminished, absolutely full and incompressible, without pores, and completely filling the space they occupy. Weight was the property emphasized in Dalton's Atomic Theory in the first decade of the nineteenth century, an age just awakening to a full understanding of an atmosphere composed of separate gases. Not until studies in electricity and radioactivity had advanced was the electron discovered as a unit much smaller than the atom and a part of every atom. Thus, in 1911, Rutherford produced the nuclear atom in which the positive nucleus determines the mass and in which the electrons revolving around it occupy more space than the nucleus itself. Finally, Planck's Quantum Theory satisfied the main objections to the idea by explaining the dual activities of the atom. The outer electron shell determines the familiar physical and chemical activities of the atom, the nucleus its radioactivity.

Fig. 152.—Charles Darwin (1809-1882). (From Garrison: History of Medicine. Published by W. B. Saunders Co.)

With each successive advance in the understanding of the atom, some cherished idea has had to be abandoned, but each advance has opened doors to new and constructive research. As a working hypothesis, the basic idea of the atom has been a successful guide, and the recent work with the cyclotron has wholly vindicated its validity.

Even so must the idea of evolution as a process of gradual improvement be accepted, as a working hypothesis to be revised and enlarged upon as more and more facts are known.

The idea can be concretely stated as follows: "Animals and plants which exist today have come into being by descent with modification from those which have existed before," and there has been a gradual increase in complexity of organization during a period of some three billions of years.

The cause of these events has ever been a closed door, but this has not hindered the philosophical mind from inquiry. Even the Greek naturalists, among whom Aristotle is the outstanding figure, had their explanations of life as a progressive phenomenon, an idea fostered now and again by the philosophers, only to be suppressed. During the early Renaissance the idea was snowed under by the diverse interests of the individual investigators. It remained for Darwin to bring the matter to a focus by the publication of the *Origin of Species* in 1859. Even history, language, literature, religion, and politics have become unified through the influence of the idea of progressive development.

The name of Charles Darwin is not revered because of the originality of his idea. Lamarck before him had formulated the first real theory of evolution, but had died before it gained the public eye. Darwin's own grandfather, Erasmus Darwin, a country doctor, but something of a naturalist and poet as well, has reference in his writing to many of the ideas involved in the natural selection theory. A contemporary, Alfred Russel Wallace, had a very similar idea which he passed on to Darwin by letter, much to Darwin's embarrassment. Only the interference of his friends kept him from making public the letter, but as it was, a joint paper was read before the Linnaean Society of London in 1858, and the *Origin of Species* was published the following year.

But precedence had no part in the influence of Darwin. It was the vast accumulation of facts covering a period of over twenty years with which he supported his theory; the cumulative evidence of little things, which brought it before the public and commanded attention. An idea, simmering since the days of Aristotle, had been brought to a focus. Whether for or against it, the public could never disregard it again. No theory since the cell theory has had so far-reaching an influence on biologic work, and not alone in biology has its influence been felt, but in all fields of human interest, bearing witness to its value as a working hypothesis.

Natural Selection Theory

There were many errors in the details of this theory and Darwin himself would have been the first to recognize them had he been in command of the volume of facts which have been brought to light since the publication of his book. In somewhat modified form natural selection is still the favored method, if anything can be said to be favored in a day of such rapid change and progress.

Darwin was profoundly influenced in his thinking by two writers: Charles Lyell, the geologist, to whose *Principles of Geology* he owed his conception of time duration; and Malthus, whose treatise *On Population* has proved stimulating to others as well.

In general the natural selection theory may be outlined somewhat as follows:

1. Nature has been prodigal in production. Any one species developing to its full potentiality could drive all other species from the earth.

2. There is always variation within the species. Some variations are better adapted to the surrounding conditions than others.

3. Because of the excessive number, an inevitable struggle will ensue.

4. In this struggle, the variations which are best adapted to the environment will survive; the less well adapted forms will perish.

5. The form which survives will be the one to mature and breed. Thus it will hand on by heredity the better adaptations, and the species will tend toward more perfect adaptation to prevailing conditions.

To sum up the idea: in the struggle for existence, the fittest will survive. In its broad outlines, the theory has great possibilities. What Darwin entirely failed to do was to account for the variations. Their presence in nature he took for granted. It is now known that the key to the problem is more likely to lie in the origin of variations than elsewhere.

Prodigality of Nature

Everyone is familiar with the phenomenon of overproduction in nature. If all the seeds which fall from the maple trees each spring were to spring up into saplings, there would be no room to walk. Fishes are known to lay millions of eggs in a season, yet the crop of fishes remains about the same from year to year, except where the depredations made by man

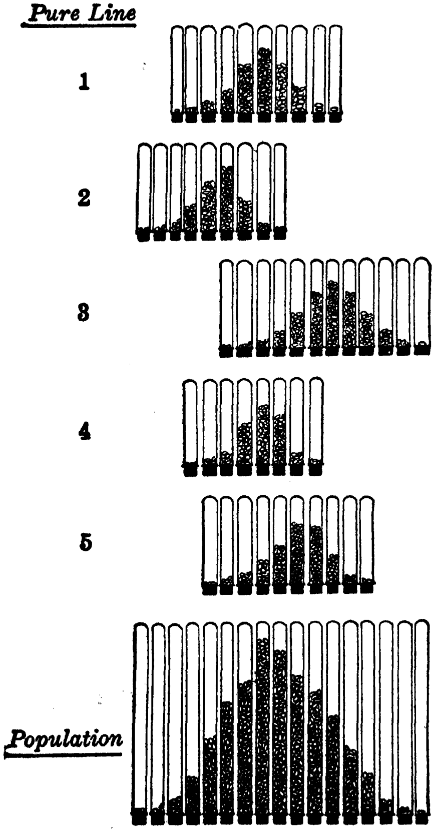


Fig. 153.—Diagrams to illustrate Johannsen's experiment with a population of beans. Beans of the same weight are placed in test tubes in the same vertical rows. The beans of the population picked at random show a curve of fluctuating variability. The five upper series represent beans selected from the population, and each series is a pure line. The mean of the pure lines is seen to vary from the mean of the population, but in no case do the extremes of the pure lines exceed the extremes of the population. (Reprinted by permission from Walter: Genetics. Published by The Macmillan Co.)

threatened the race with extinction. The egg of the ling, which lays 28,000,000 eggs in a season, has one chance in 14,000,000 to develop into an individual.

Darwin calculated that a single pair of elephants beginning to breed at thirty years of age and continuing to do so until a century old would produce on an average six young, and would have in 750 years, barring accident, 19,000,000 descendants. And the elephant is the slowest breeder known.

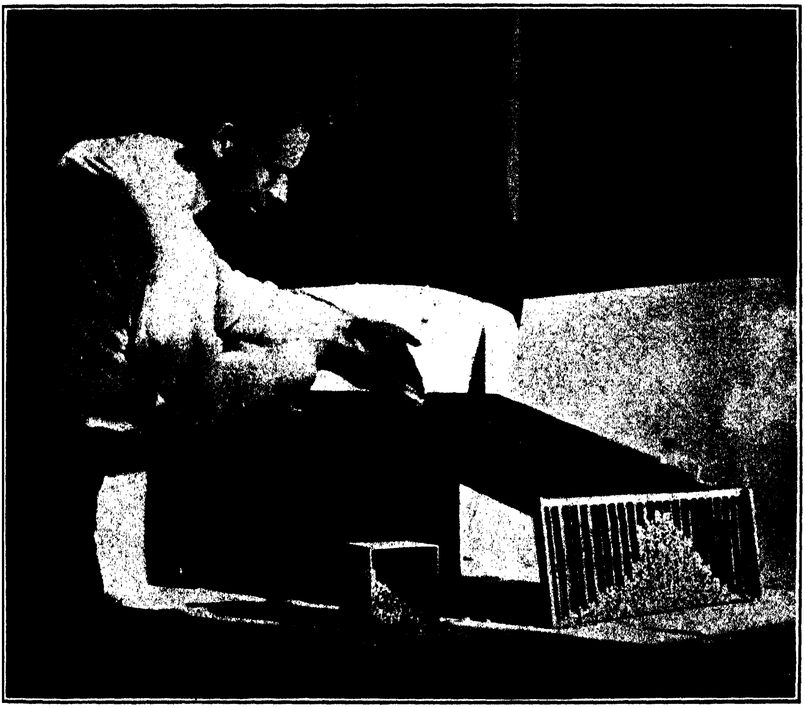


Fig. 154.—Photograph from A. F. Blakeslee showing a normal variability curve following the law of chance. The beans are rolled down an inclined plane and accumulate in compartments which are closed in front by glass. The exposure of the photograph was long enough to show the beans as elongated objects moving across the board. The laws of chance lead to the expectation that very few beans will swerve to the edges of the board, the majority tending to accumulate near the center, with about equal numbers swerving to right and to left. The resulting curve resembles the curve in Johannsen's experiment. (Reprinted by permission from Popenoe and Johnson: Applied Eugenics. Published by The Macmillan Co.)

Huxley has made some equally famous calculations, finding that the descendants of a single fly would, at the end of a summer, outweigh the population of China. The oyster, which may lay as many as 60,000,000

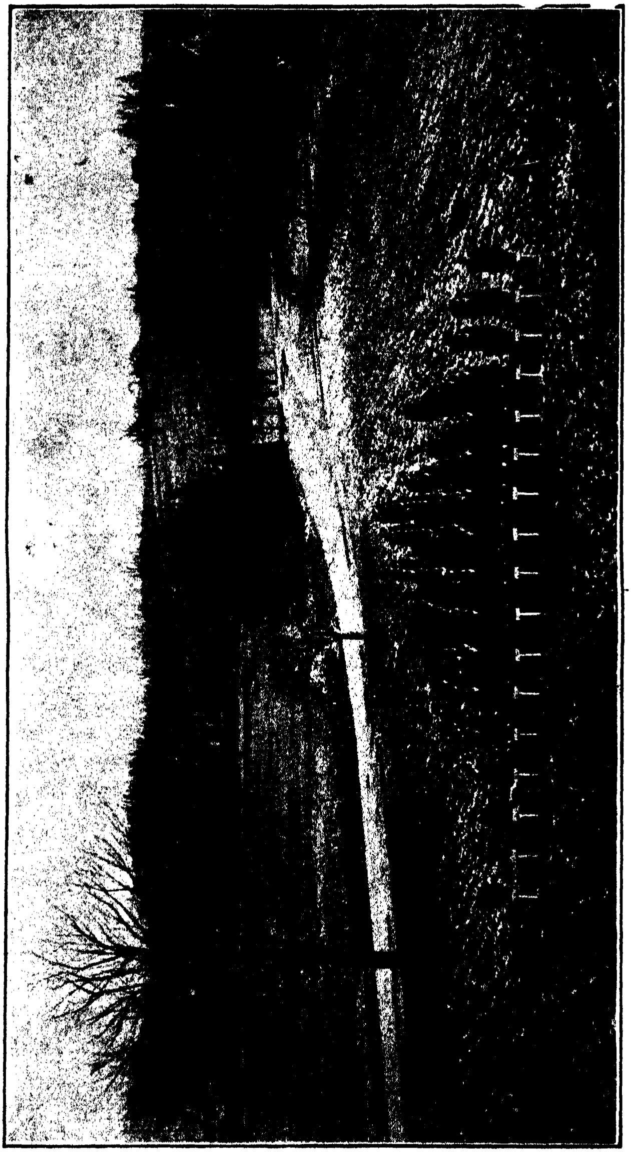


Fig. 155.—Cadets arranged according to height to show a normal curve of variability. A company of students at Connecticut Agricultural College photographed by A. F. Blakeslee. (Reprinted by permission from Popenoe and Johnson: Applied Eugenics. Published by The Macmillan Co.)

eggs in a season, would, if all the progeny survived to the great, great grandchildren, number 66,000,000,000,000,000,000,000,000,000,000,000; and the heap of shells they would make would be eight times the size of the earth.*

Variation

There is nothing so invariable in nature as variation. No two leaves on a tree, no two violets in a field, no two animals in a brood, are absolutely and identically the same. In a large family there is tendency for all to resemble the parents, the family likeness with which we are all familiar; yet, even in the case of identical twins, the mother can distinguish between them. These variations are partly due to the environment, such as varying conditions of development, of nourishment, and of climate; and partly they are due to heredity. For there is a tendency to variation recognized in many hereditary characters, such as height and weight and color of the hair and eyes.

In any large aggregation, such as a college class, or a quart of beans picked at random, the members of the group will be found to arrange themselves around a curve of probability, there being more members of mean size or mentality than of either extreme. Occasionally there occurs an individual so different from the rest as to fail to fit into the established curve. Such a variation is the white-eyed fly which appears in a flock of pure bred red-eyed ones. This is known today as a *mutation,* and is probably more effective as a factor in natural selection than the continuous or fluctuating variations.

Nature's Balance

Probably no one of Darwin's illustrations has been more fruitful than that which shows the interrelations of plants and animals, more recently called "the web of life." No species exists which has not some natural enemy which operates to keep its numbers down.

Darwin's example of the relation between cats and clover has become a classic. Bees are known to be indispensable to the fertilization of clover from which they collect the pollen on their legs when they go to gather the flower sap for honey. The number of bees in any district is determined by the number of mice which destroy their combs and nests. Cats destroy mice. Thus the number of cats in any district would determine the number of clover blossoms in that neighborhood. Huxley has added a link to each end of this chain by suggesting that cats are usually harbored by spinsters, and that the clover forms a diet for the cattle which in turn form a main staple of the diet of England's sons; thus making the maiden ladies in a community responsible in this very roundabout way for the welfare of the ''roast beef of Old England.''*

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*Data from Lull.

Destroying the Balance

Man, in his ignorance of nature, has many times unwittingly upset the balance of nature to his own cost. How many times have we asked the question: whence comes the parasite that spreads the new and treacherous disease? The answer probably lies in the fact that the normal habitat of the parasite has been removed, and it has found a new and more favorable environment in a host which harbors none of its own natural enemies. It is an amazing comment on the balance of nature that these most minute of all living things, and possibly the first to evolve out of inorganic matter, should be the most deadly of the enemies of man who has conquered so many of the elements of nature.

But the trouble is that man's intelligence has not been proof against mistakes. The cost of his mistakes could not be counted in trillions of dollars. The introduction of rabbits into Australia, of sparrows into America, and rats into Jamaica; the thoughtless destruction of trees, birds, spiders, and snakes —these are but a few of the errors that have proved more costly than their apparent insignificance would seem to warrant.

Sometimes the introduction of animals into novel environments is done purposely. A pair of English sparrows was brought from England in 1851. It was thought they might rid the shade trees of New England of the inchworm, but they have so adapted themselves to our dooryards that they have driven many more desirable birds into the woods.

More often it is done accidentally, as when rats escaped from the ships at the docks in Jamaica. They soon became such pests in the surgar cane fields that the mongoose was brought from India where it was known to feed on rats, lizards, and snakes. The mongeese increased so rapidly that as the rats diminished they found new sources of food in the livestock on the farms. They attacked the young of so many species, both domestic and wild, that many once common species became practically extinct. With the loss of insectivorous birds, injurious insect pests increased, especially the tick, which became most destructive. The mongoose, too, took to eating bananas, pineapples, coconuts and other valuable crops, until in twenty years it had become the worst pest on the island. There is no end to the cycle when once you destroy a thread.

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*Lull.

Occasionally such importations are successful, especially if scientifically controlled. In California, ladybugs have been imported to combat the mealy-bug pest of the citrus fruits. Ladybugs are apparently harmless in other respects, and, since they have failed to thrive in sufficient numbers, a regular business has been developed, with the raising of ladybugs as its sole aim. Mealy bugs are raised in controlled captivity to furnish food for millions of larval ladybugs. Development can be delayed by placing the larvae in cold storage, and metamorphosis timed to coincide with the activities of the pests in the orange groves.

The walnut growers of California have established nurseries for a minute wasp, Trichogramma, which parasitizes the eggs of the coddling moth. It can be cultivated easily on the eggs of grain moths, since Trichogramma does not require any specific egg in which to lay. The eggs are sprinkled on stiff, shellacked paper. This is cut in strips and presented to the Trichogramma females under glass. When parasitized, the strips are placed in mailing tubes to be sent anywhere in the United States where the little insect is needed. Since it is not particular what egg it attacks, it bids fair to be helpful in the controlling of many pests, especially those which lay their eggs in the open.

Inheritance of Acquired Characters

Jean Baptiste Lamarck (1744-1829), a contemporary of Darwin's grandfather, was the first to formulate a real theory of evolution, but like many another, he lived only to see the idea ridiculed, and it was long after his death, when the *Origin of Species* had brought the matter to a focus that his *Philosophie Zoologique* came into its own. Today a group of Neo-Lamarckians are still endeavoring to show that the inheritance of acquired characters is not only a possibility but a fact.

The key to this theory is the direct action of the use and disuse of parts, according to Lamarck. It is a well-known fact that muscles develop under usage and shrink from lack of use. The skin exposed to the sunlight takes on a coat of tan, the fingers acquire skill with practice. It was Lamarck's fancy that these acquired conditions were handed down direct and unaltered to the next generation. This is what is now known as the inheritance of acquired characters.

The giraffe, which is known to have descended from a short-necked, deerlike ancestor, is thus supposed to have acquired his long neck. The richer foliage is higher in the tree than the giraffe can normally reach, so he puts forth extra exertion and thereby eventually lengthens his neck very slightly. His offspring are born with longer necks and the good work goes on.

Darwin would have explained this same phenomenon by assuming that there were variations in the necks among the deerlike ancestors. The one with the slightly longer neck was thus able to reach the leaves which were farther from the ground, and, being better nourished, was stronger and more vigorous than his brothers. He was, therefore, more successful in the struggle for existence and lived to have offspring which also had necks of varying lengths but with a longer mean than before.

Continuity of the Germ Plasm

Darwin, in his later writings, subscribed to Lamarck's idea of the inheritance of acquired characters due to the effects of use and disuse, and evolution came thus to be pictured in the public mind with many strange and fantastic accompaniments. It flourished until challenged by August Weismann (1834-1914), a German scientist, who proved a true prophet by describing in advance of the discovery, all that takes place in the chromosomes during the reduction division.

Weismann's contribution to science was the theory of germinal continuity. The cells of an organism are of two kinds: the somatic cells, or *somatoplasm* from which the organs of the body are developed, and the *germ plasm*, the undifferen-

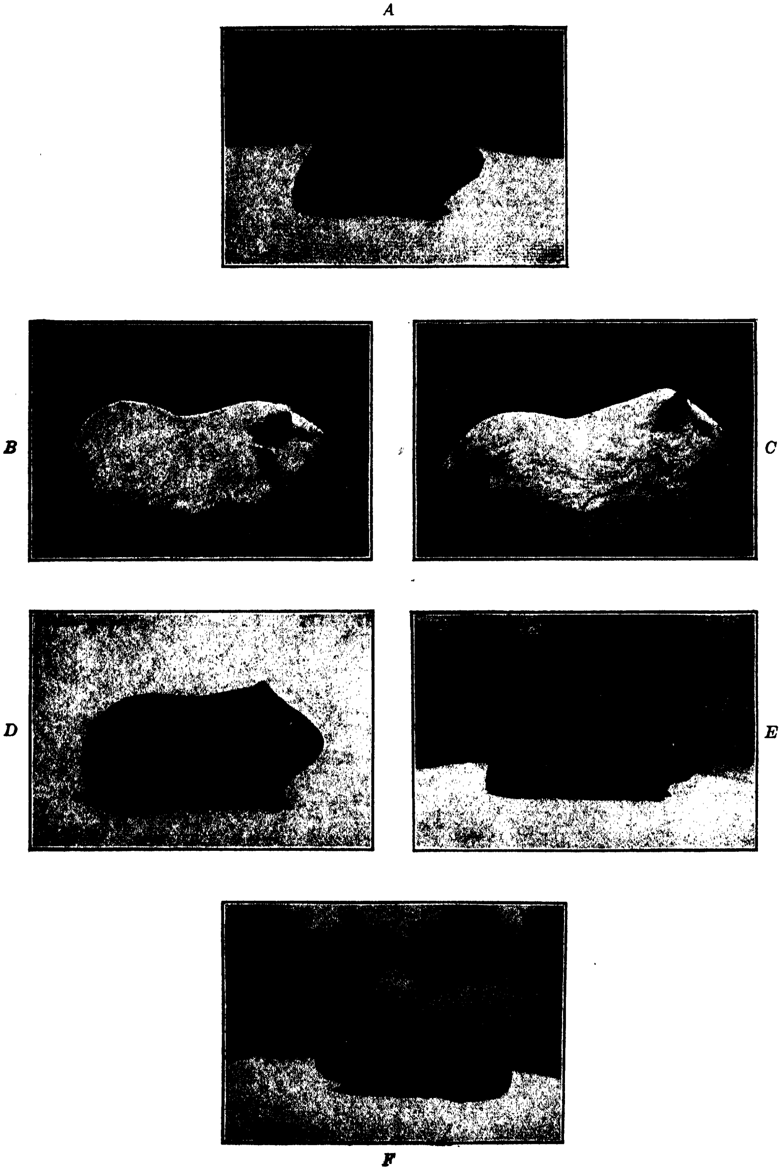


Fig. 156.—Results of ovarian transplant in guinea pigs. Ovaries from a small black guinea pig (*A*) were transplanted into an albino (*B*), which, mated with another albino (*C*), produced black young (*D, E, F*). (Reprinted by permission from Castle: Genetics and Eugenics. Published by the Harvard University Press.)

tiated cells which carry the potentiality of the next generation, and which reside in, but are not a part of, the body. These cells arise as direct descendants of the germ cells of the previous generation, and carry in them the potentiality of all future generations. Thus the germ plasm forms a continuous stream from generation to generation, and the inheritance of acquired characters as Weismann pictured them is quite out of the question. Whether any possibility exists of influencing the germ cell direct, as the recent experiments of Muller with x-ray seem to indicate, or indirectly by injury through the blood stream carrying hormones of various types, is for the future to settle.

Probably the most outstanding proof of the continuity of the germ plasm and the isolation of the germ cells in the body was accomplished by Castle and Phillips. They transplanted the ovary of a young black guinea pig into a pure white albino female after first removing her ovaries. These albinos had bred true for many generations. When the female had matured, she was bred to a pure albino male. If the ovaries were affected by her somatic cells, there should have been some signs of white in the offspring, but they were as pure black as the guinea pig from which the ovaries had been taken. This furnished conclusive proof that somatic modifications are not transmitted to the germ cells.

CHAPTER XVII

SOME PROBLEMS OF THE TWENTIETH CENTURY

The Mutation Theory

Until 1900 the main result of Darwin's theory was to create speculation and argument among its followers. The twentieth century inaugurated a new mode of attack in the experimental method, a method brought to the fore in that year by the discovery of the laws of hybridization. Fortunately, these laws were traced back to the original experimenter, Gregor Mendel (1822-1884)—see page 264.

Mendel's experiments were published in 1863, so soon after the publication of the Origin of Species that, had the paper been brought to the attention of Darwin, it is probable its influence would have been seen in his natural selection theory. As it was, the paper remained in obscurity until 1900, when the publications were distributed to the libraries of Europe.

Three botanists, Correns, Tschermak, and DeVries, made the discovery almost simultaneously; but the name of Hugo DeVries became immortalized by the application he made of the mendelian laws in the mutation theory. In his gardens in Amsterdam, experimenting on the evening primrose, Oenothera, he found that many variations occurred which differed so radically from the parent plant that they could not be accounted for under the heading of Darwin's fluctuating variations. These variations, when inbred, proved stable, and behaved in crosses according to the expectations marked out by Mendel. These discontinuous variations he called *mutations,* in the belief that the processes of evolution would have been greatly shortened if species had been initiated by discontinuous rather than continuous variations.

So important was the work of DeVries that the experimental method has dominated all subsequent work in this field, and the science of genetics was initiated. Attempts to find mutations and to prove the mendelian hypothesis have brought about many alterations in the laws first formulated, but the conclusions of the original author have been brilliantly verified. This verification has been extended to the chromosome theory also, and the absolute coincidence of chromosome behavior with experimental data has been one of the most brilliant demonstrations of the century.

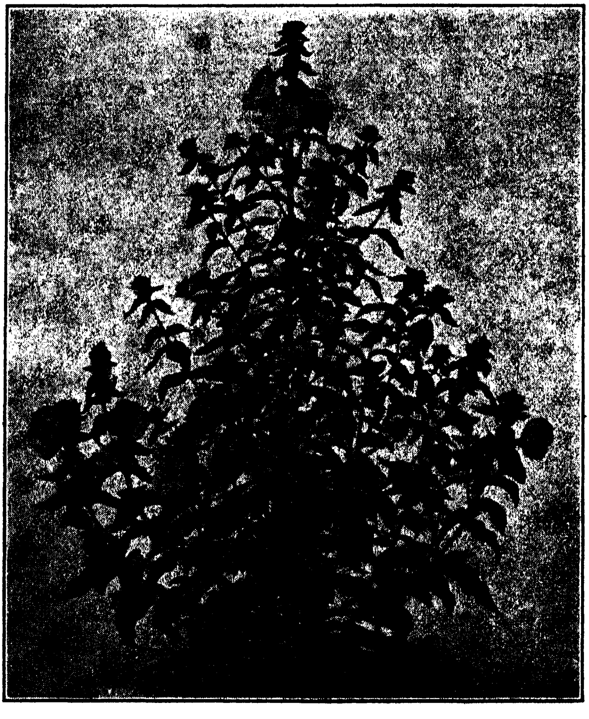


Fig. 157.—*Oenothera lamarckiana.* (From De Vries, Gruppenweise Artbildung, Gebrüder Borntraeger, 1913.) (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

The Theory of the Gene

The twentieth century has already several outstanding landmarks of achievement in the field of genetics. T. H. Morgan made a contribution of untold value when he discovered that the fruit fly, Drosophila, was in a mutating condition. Over two hundred hereditary factors have been identified in Drosophila, and these have been linked into four groups corresponding definitely with the four pairs of homologous chromosomes. The dis-

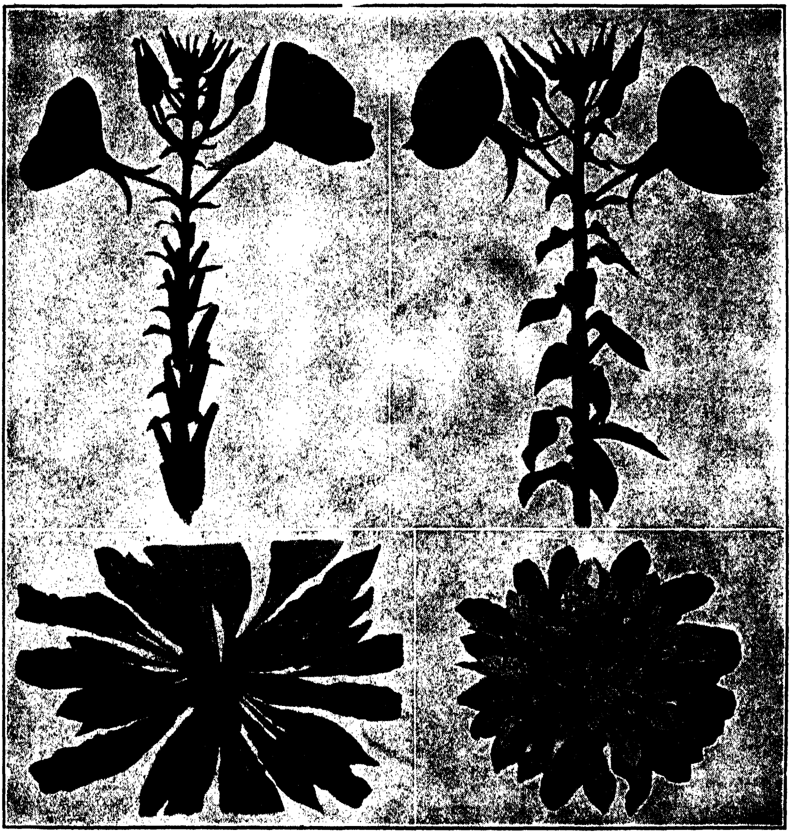


Fig. 158.—*Oenothera lamarckiana* (left) and Gigas (right), flower stalks and rosettes. (From De Vries, *Mutationstheorie*, ed. 1, Von Veit & Co., 1901; Gruppenweise Artbildung, Gebrüder Borntraeger, 1913.) (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

covery that the linkage of these groups is not absolute has made possible the extension of the chromosome theory to the gene theory, in which the location of the factor on the chromosome has been accomplished. The granular structure of the prophase chromosomes gives cytologic corroboration to the idea of the separate granule, or chromomere, as the seat of the individual factor, or gene, and, while it has never been possible clearly to demonstrate the method of separation of homologous pairs of chromosomes, experimental evidence proves that factors may cross from one homologous chromosome to the other.

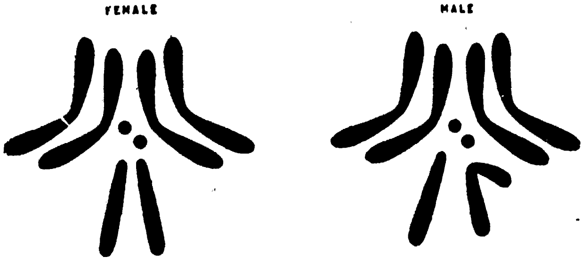


Fig. 159.—Diagram to show the characteristic pairing, size relations, and shapes of the chromosomes of *Drosophila melanogaster*. In the male an X- and a Y-chromosome correspond to the X-pair in the female. On the basis of X equals 100 the length of each long autosome is 159, of each small autosome 12, of the whole Y equals 112, the length of the long arm of the Y 71, and of the short arm 41. (After Bridges.) (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

It is now possible to picture chromosomes, showing the relative position of any one gene to any other on the chromosome in linear alignment. This mapping of the gene in Drosophila, chiefly due to Sturtevant, is based on the relative number of times any gene crosses from one homologous chromosome to the other, when mated with a gene of known location. This is known as *linkage*.

Induced Mutations

The year 1927 established another landmark in genetic history when Muller demonstrated that the mutations normally occurring could be induced at a far greater rate by the penetration of x-rays. Since that time many external agents have been used successfully to induce mutations. These include gamma rays, ultraviolet rays, cosmic rays, and such chemicals as colchicine and granosan. Aging of seeds and temperature changes have been effective in changing the rate of crossing over between homologous chromosomes.

Cytologic studies of the chromosomes in induced mutations have shown broken and rearranged segments of chromosomes and the doubling and tripling of chromosome number to be among the effects of external penetration.

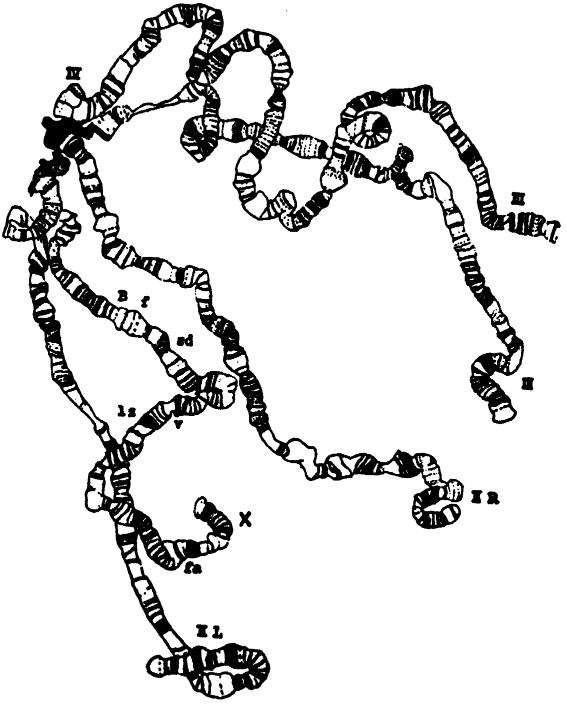


Fig. 160.—A salivary chromosome group from *Drosophila melanogaster*. (From Morgan. After Painter.)

Salivary chromosomes which are large enough to be drawn out of the cell have played a dramatic part in increased accuracy of gene mapping. Painter's perfection of the technique of removing them from the cell and stretching them in glycerine has made it possible to identify gene locations on the maps with actual positions on the chromosomes.

Recent Trends

Today the gene itself is coming more and more into the foreground as a chemical entity. It has taken its place with the many activators of metabolic reactions, as a protein molecule with the properties of self-propagation and mutation. In these respects it is so similar to the virus that virus molecules are now believed to be chromatic material and to represent the possible pro-gene in organic development.

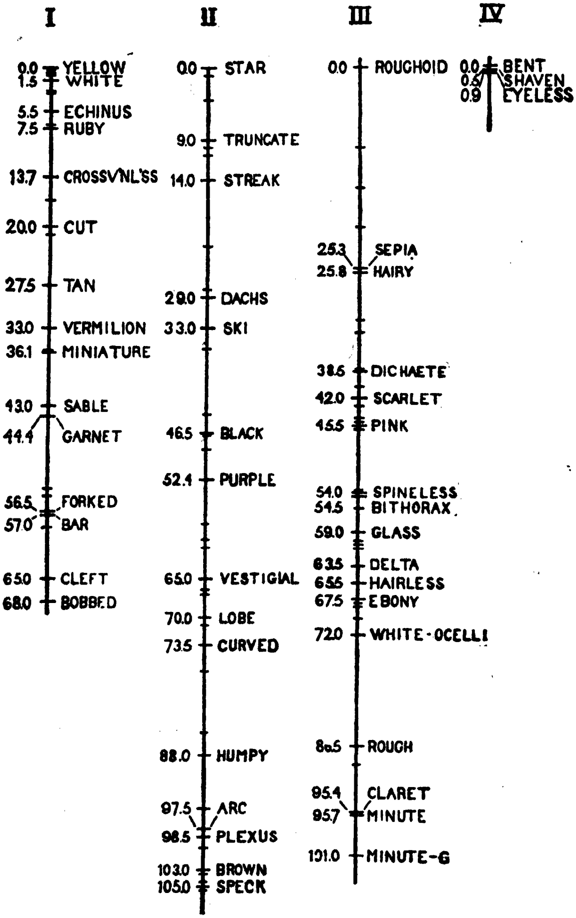


Fig. 161.—Maps showing the loci of some of the factors in the four linkage groups of *Drosophila melanogaster.* (After Morgan.) (Reprinted by permission from Babcock and Clausen: Genetics in Relation to Agriculture. Published by the McGraw-Hill Book Co.)

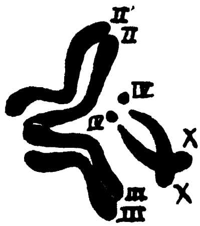


Fig. 162.—The normal chromosome complex of a female Drosophila drawn with the aid of a camera lucida. Compare with the groups in the next figure. (From Painter and Muller. Courtesy of the Journal of Heredity.)

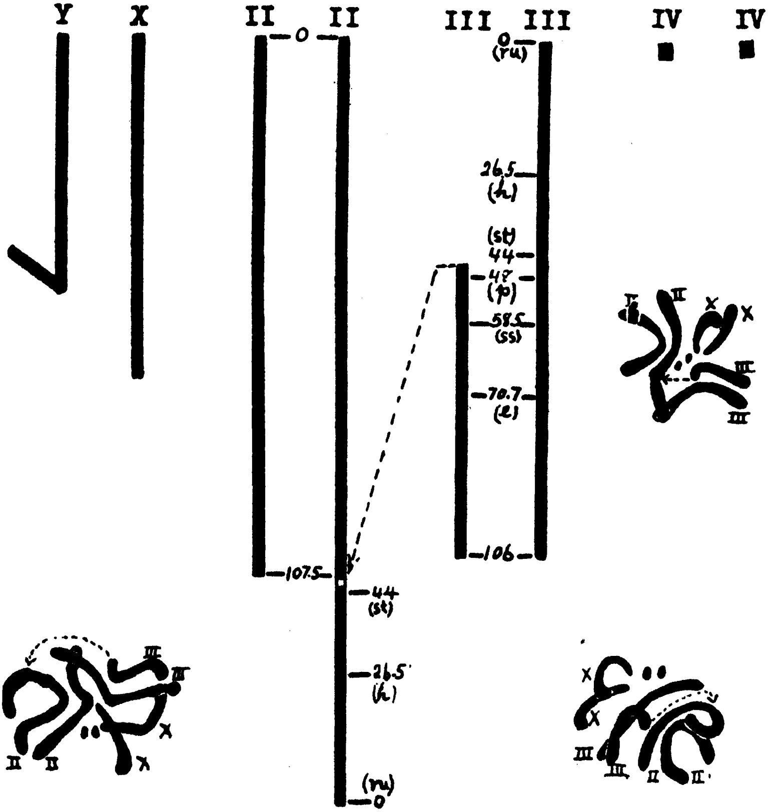


Fig. 163.—Translocation of a portion of the third chromosome of Drosophila to the lower end of a second chromosome. The break is between the locus of scarlet (*st*) and pink (*p*). The chromosome groups compared with the normal complex in the preceding figure show that one of the third chromosomes is shorter, and one of the second chromosomes longer in each case. (From Painter and Muller. Courtesy of the Journal of Heredity.)

PART III

PROGRESSIVE ORGANIZATION

SECTION I

PLANT KINGDOM

CHAPTER XVIII

ORGANIZATION OF PLANTS

In the plant kingdom, a study of progressive organization necessarily involves following two types of tissue, for the reproductive tissues have shown a steady reduction as the vegetative tissues have gained in importance and showiness. Classifications, in general, tend to follow the reproductive organs, since these have been less subject to environmental change than the vegetative. The vegetative structure has shown equally instructive progression, however, and in its adaptation to aerial life has developed an organization quite as successful for its type of life as the bilateral type was for animal life. In the plant, however, symmetry has played a secondary part.

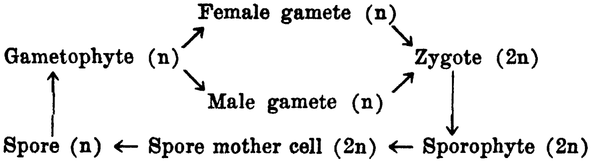
PLANT GENERATIONS

Two types of reproductive cells are formed in plants, the gametes, which are typically dimorphic and must unite before development, and the spore, which develops independently. Both types of cells have the same number of chromosomes known as *haploid*. The number is doubled by union of the gametes and becomes *diploid* in the zygote.

The tissues from which the gametes develop have the haploid number of chromosomes; the tissues from which the spore develops have the diploid number. This involves a reduction in number which is accomplished by a special cell called the spore mother cell. The process is called *meiosis* and is described in detail in Chapter XIII. The spore thus has again the haploid number.

Vegetative tissues of the plant which have the haploid number are known as *gametophyte* tissues; those which have the diploid number are *sporophyte* tissues.

There is thus an *alternation of generations* in the plant kingdom. The gametophyte forms the gametes which by their union form the sporophyte. The sporophyte produces a spore mother cell which by reduction forms the spore. The spore forms the gametophyte tissue.



In the simple plants known collectively as the Thallophytes, the plant is a gametophyte. The spore is formed within a thick-walled zygote and no sporophyte plant is formed.

In all higher plants, a plant with sporophyte tissue is interpolated between the gametes, and the spore and the vegetative tissues of this plant have become progressively more successful in adaptation to aerial life.

The problems met by aerial life include a decreasing source of water supply and an increasing difficulty in the dispersal of the species. Tissues began to differentiate: epidermal tissues for the conserving of the water supply, vascular tissues to facilitate water conduction, and parenchyma tissue for the storage of foods. Thus the sporophyte plant became of progressively greater importance, and gradually came to replace the gametophyte as the dominant vegetative plant.

As the sporophyte gained independence, a gradual reduction of fertile tissue took place, centralizing the reproductive processes until adaptations arose which increased the effectiveness of the organs themselves, and structures adapted to air and insect pollination finally replaced those adapted to swimming sperms. The flower marks the final reduction of fertile sporophyte tissue and the complete reduction of the gametophyte to a parasitic structure.

The dominance of the sporophyte plant has been progressive, and the plan adopted for the study of the plant kingdom follows this progression.

Two terms are used to denote the vegetative structures: the *thallus* type and the *vascular* type. The terms are not wholly descriptive. Thallus is a loose term applied to any vegetative structure without true roots, stems, and leaves, and, in general, corresponds with the gametophyte vegetative structure. True vascular tissue and roots, stems, and leaves appeared simultaneously with the independence of the sporophyte plant, yet the adaptations of the first aerial gametophyte plants show some intercellular air spaces and some elongated conducting cells which simulate vascular tissue. True vascular tissue involves the establishment of continuous pathways of conduction between the roots, stems, and leaves which enabled the tissues to rise further from the source of water supply. Roots, growing through the soil, follow water for long distances if necessary, and the vascular plants are able to live in relatively dry regions. The development of secondary growth tissues with the power of cumulative increase made possible greater length of life and survival over long periods of unfavorable conditions. The success of the type is indicated in the long life of the California redwood trees, and in the great variety and wide distribution of the flowering plants.

The plan for the study of progressive organization, as followed in the succeeding chapters, is based on the increasing success of the vegetative tissues. The general plan is outlined below.

- **Thallus organization (without roots, stems, or leaves)**
  - **Unicellular type: Bacteria, blue-green algae, one-celled green algae**
  - **Filamentous type: Filamentous algae and fungi**
  - **Flat thallus type: Liverworts and hornworts**
  - **Leafy thallus type: Mosses**
- **Vascular organization (with roots, stems, and leaves)**
  - **Spore-bearing type: Pteridophytes**
  - **Seed-bearing type: Spermatophytes**
    - **Cone-bearing: Gymnosperms**
    - **Flower-bearing: Angiosperms**

The reversal of dominance from the gametophyte to the sporophyte plant with its consequent reduction of fertile tissue is briefly indicated by these five steps:

1. Unicellular thallus type:	Sexual reproduction absent or specialized.
2. Filamentous thallus type:	Plant a gametophyte; sporophyte, if present, a mere zygote.
3. Flat thallus type:	Independent gametophyte; dependent sporophyte.
4. Leafy thallus type:	Independent gametophyte; dependent sporophyte.
5. Spore-bearing vascular type:	Independent gametophyte; independent sporophyte.
6. Seed-bearing vascular type:	Dependent gametophyte; independent sporophyte.

CHAPTER XIX

THALLUS ORGANIZATION

FILAMENTOUS TYPE

True alternation of generations is not definitely established in the filamentous types, but several types of sexual reproduction occur which approach the condition. In general, the filament can be considered a gametophyte; the sporophyte, if represented at all, exists as a zygote.

Reproduction may be by isogamy (union of like gametes), or by heterogamy (union of unlike gametes). As in the Protozoa where similar types are found, union of like gametes is called conjugation, of unlike gametes, fertilization.

Isogamous types may have swimming gametes with motile elements, or creeping gametes which move by means of contractions in the vacuoles. The terminology of the motile elements lacks any uniformity. The protozoologist recognizes two different types: the flagellum which is long and whiplike and the cilia which are short and delicate, functioning as a group rather than singly. Both have axial filaments and arise from blepharoplasts in the cytoplasm of the cell. The botanists use the two terms synonymously, but call the motile elements of the swimming gametes cilia. It will be necessary to follow this terminology to avoid confusion with other texts, though the cilia of the zoospores are apparently the same type of element as the flagella of the flagellates.

AN ISOGAMOUS TYPE

Ulothrix

Ulothrix is one of the common green algae found in fresh water streams. The filament is of simple organization, and differs from the strictly colonial types only in the possession of a holdfast which is developed from the basal cell to anchor the filament to a substratum. The apical cell is rounded. Otherwise, every cell is like any other.

Each cell contains a nucleus and a band-shaped chloroplast, which is wound about the periphery so as to leave a central vacuole. Elongation of the cell is accomplished by the absorption of water into the vacuole. Multiplication of cells occurs between the apex and the base, a type of growth known as intercalary, as distinguished from apical growth.

Life Cycle.—The filament of Ulothrix is a gametophyte. It may be reproduced either asexually or sexually. In the former case motile zoospores are formed; in the latter case, gametes. Any cell of the filament may form zoospores, and any cell may produce gametes. They may even occur on the same filament, though this is rare.

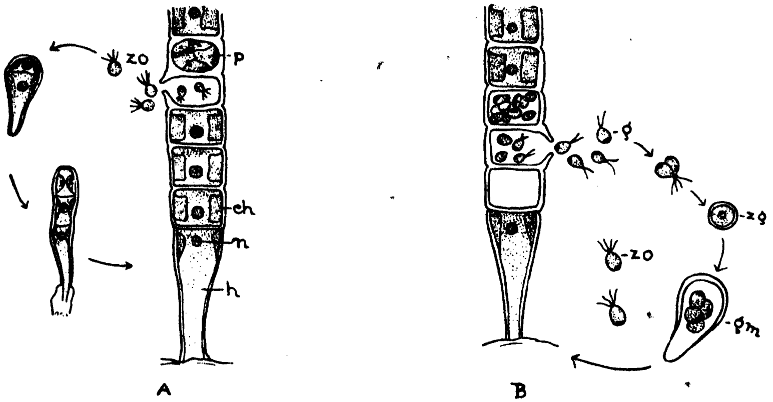


Fig. 164.—Diagram showing the life cycle of Ulothrix. *A*, Asexual cycle; *B*, sexual cycle; *ch*, chloroplast; *n*, nucleus; *h*, holdfast; *p*, protoplast forming zoospores; *zo*, zoospore; *g*, gamete; *zg*, zygote; *gm*, germinating zygote with zoospores.

The zoospores have four cilia. They are formed in any cell where the entire protoplast takes part in their formation. There may be but one, or there may be as many as eight. The spores escape through an opening in the cell wall, and swim about for a time before settling down on a substratum to form a new colony. The gametes are formed in a similar manner, but each has but two cilia. They are all alike (isogamy), and are unable, except in rare cases, to develop without conjugation. When they do so develop, it is a case of parthenogenesis (see Chapter XIII).

The union of like gametes is called conjugation, and the zygote is the sporophyte generation of the plant. It forms a heavy, resistant wall, and further development is delayed until conditions are favorable for germination.

Upon germination at least four zoospores are formed, similar to the asexual zoospores. These develop new filaments.

A HETEROGAMOUS TYPE

Oedogonium

Like Ulothrix, Oedogonium has a basal anchoring cell. The cells are elongate, however, being longer than broad. The single peripheral chloroplast is net-shaped.

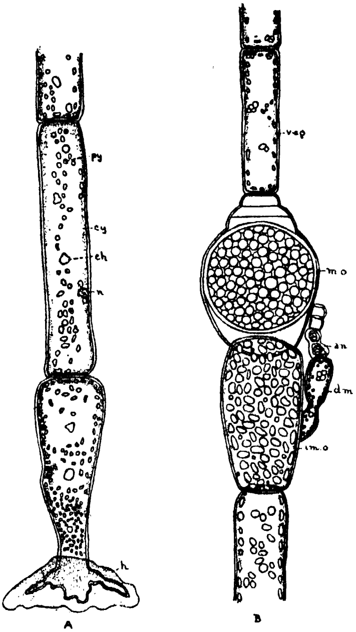


Fig. 165.—Oedogonium. *A*, Filament showing vegetative cells and holdfast cell. *B*, Filament with dwarf male attached. *py*, Pyrenoid; *cy*, cytoplasm; *ch*, chloroplast; *n*, nucleus; *h*, holdfast; *veg*, vegetative cell; *m.o.*, mature oögonium containing a ripe oöspore; *im.o.*, immature oögonium; *dm*, dwarf male; *an*, antheridial cells.

Not every cell may form zoospores; but those which do, usually produce but one. This is large and has a crown of cilia. It escapes and grows a new filament.

Sexual Reproduction.—The gametes are unequal and are formed in different cells or even on different filaments. The female cells are produced inside the *oögonia*. Each enlarges to become a single large egg, perforated for the entrance of the sperm. A large amount of food material is stored up in the egg.

The male gametes are formed in antheridia. The cells divide without elongating, and each may produce one or two sperms. These have crowns of cilia like the zoospores, but are much more minute.

In some species the male cells are formed on a separate filament, and in that case the male filament becomes attached to the female filament and produces very few cells, so that they are called the dwarf males.

Fig. 166.—A fruiting filament of Vaucheria, a form similar to Oedogonium but without cross walls. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

Union of two unlike gametes is by fertilization, and only the nuclei of the two cells unite. The zygote has a heavy wall, and upon germination it forms four zoospores which develop new filaments.

A FUNGOUS TYPE

Rhizopus

Rhizopus nigricans is one of the black molds which grow profusely on breads and fruits. It belongs to the Phycomycetes, a group of fungi which closely resembles the green algae, although lacking in chlorophyll. This lack of chlorophyll is not primary as in the bacteria, but is a secondary adaptation to the dependent mode of life. The molds in general are saprophytes.

Rhizopus is an isogamous type without zoospores, and has a type of conjugation very similar to that of Spirogyra.

The filaments of fungi are called *hyphae.* In the Phycomycetes these are lacking in cross walls, a condition known as *coenocytic.*

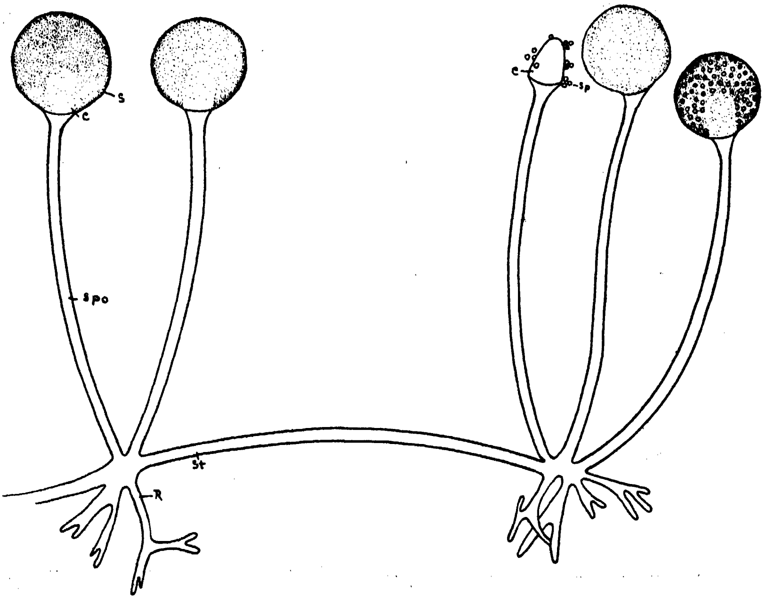


Fig. 167.—*Rhizopus nigricans.* Sporangiophores with rhizoids and a connecting stolon. *Spo,* Sporangiophore; *st,* stolon; *R,* rhizoids; *s,* sporangium; *c,* columella; *sp,* spores.

The hyphae of Rhizopus are of three types.

1. **Rhizoids.**—These grow down into the substratum, to form an anchor. They are branching, and they secrete enzymes which digest the food provided by the tissues of the host. After digestion, the rhizoids absorb the food.

2. **Stolons.**—These are larger filaments which grow parallel to the substratum and make another contact with it. At the point of contact, a group of rhizoids grow down into the substratum. Thus the plant spreads over a large area in a short time.

3. **Sporangiophores.**—These are erect hyphae which grow up from the point of contact with the substratum. They form the spores.

The profuse branching of the hyphae forms a mycelium which gives the fluffy white appearance to the mold.

Spore Formation.—The spores are formed by the sporangiophore, in the globular *sporangium* which develops at the tip of the erect hypha. The protoplasm in the sporangium concentrates at the periphery, leaving a thin, vacuolated protoplasmic mass in the center.

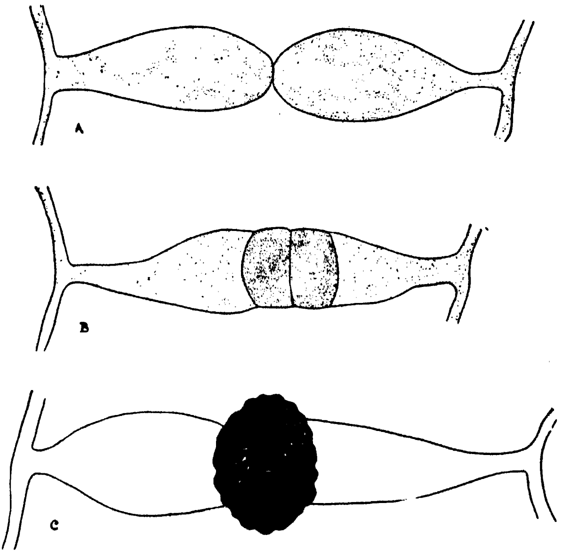


Fig. 168.—*Rhizopus nigricans.* Stages in the development of the zygospore. *A,* Union of two hyphae. *B,* Fusion of the coenogametes. *C,* Zygospore.

The vacuoles in the inner mass are then arranged in a dome-shaped layer between the inner and the outer masses. They flatten out and unite to form a cleft between the masses. The cleft has a plasma membrane on each side, formed from the membranes of the vacuoles which have joined. A wall is secreted between the two membranes, and a dome-shaped columella is formed.

The dense outer protoplasm is then the *spore sac.* It contains many small nuclei, and is shortly divided up into a series of protoplasts of irregular shape by furrows which cut through the protoplasm.

Each protoplast is a multinucleate *spore*. It forms a thick black wall of cellulose which secretes a mucilaginous substance very resistant to drying, but dissolving easily upon contact with water. These spores are present in the air all the time except just after a shower, so that the exposure of the damp surface of bread or fruit to the air will raise a culture of the mold in a short time.

Sexual Reproduction.—Zoospores are absent, and conjugation occurs between filaments. The contact is made at the tips of two hyphae, each of which contains a single multinucleate gamete, a coenogamete. The walls of the hyphae dissolve at the point of contact and the two gametes fuse.

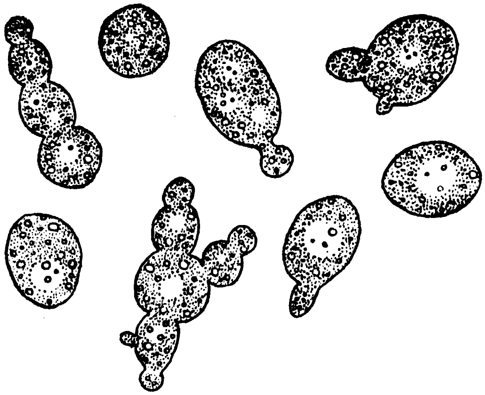


Fig. 169.—Yeast cells budding.

The zygote, which is the sporophyte, develops a thick black wall. At the end of the resting period it sends out an erect hypha at the tip of which is a sporangium. The asexual spores produced in the sporangium reproduce the gametophyte.

There is a slight sexual differentiation, but not between the hyphae of one plant. It is necessary that two strains or races of Rhizopus be growing together for conjugation to take place. The difference between the hyphae is an intangible one, and the strains have been called plus and minus. The plus strain has more vigorous growth than the minus strain, but there is no apparent sexual differentiation.

Asexual reproduction will continue indefinitely in the absence of the conjugating strain. If conjugation does occur, both strains will be present in the zygote, and these will be segregated during the reduction division so that the spores will form both plus and minus types.

Yeasts

Yeasts are also fungi of the class Ascomycetes (sac fungi). They are one-celled forms, but the indications are that they are a specialized group which have descended from a more complex variety of ascomycete.

The Ascomycetes are characterized by spore sacs which form *ascospores*. The spore sac is an *ascus*.

Yeasts are very widespread in nature, living on the surfaces of fruits, in digestive cavities of animals, and even in the cells. Their interest lies in their commercial value as agents of fermentation. Yeasts are used at the present time for general stimulation of the digestive tract, and as a source of vitamins. Commercially, they are used for the raising of bread doughs, and for the manufacture of alcohols. There are cultivated and wild species, and the wild forms often infect the cultivated cultures to the brewer's despair.

The yeast cell is ovoid. There is a definite nucleus, and a large vacuole surrounded by a granular cytoplasm. The starch formed is *glycogen* as in the blue-green algae. Oil drops are also formed. The cell wall probably consists of chitin, though some claim that cellulose is present.

Reproduction.—Yeasts multiply by a process of *gemmation*, new cells being budded from the sides of the old. These often remain in contact forming sprout chains.

In the presence of an excess of oxygen, spore formation takes place. When this occurs the yeast cell functions as a spore sac, or ascus. The protoplasm divides to form four cells, or occasionally more, each with a single nucleus. These are the ascospores. They absorb water, and grow until they break the cell wall, when they escape and form new yeast cells. Except in a few species no union of gametes occurs.

CHAPTER XX

THALLUS ORGANIZATION (Cont'd)

FLAT THALLUS TYPE

The transition from the thallophytes to the bryophytes marks a decided advance in plant organization, for with it comes the adaptation of the plant to a semiterrestrial life. The bryophytes are found typically in damp, shady places, but have an aerial structure, the gametophyte, which has tissues with intercellular air spaces. The sporophyte develops as a parasite on the gametophyte plant. Thus the true alternation of generations of the plant kingdom is definitely established, and from this point on there is a gradual reversal of relationships between the two generations.

The bryophytes include the liverworts and mosses. The liverworts have the flat thallus, and the mosses the leafy thallus.

Marchantia

Marchantia is a rather specialized liverwort in which the tissues of both gametophyte and sporophyte are well established. The gametophyte is a flat, lobed *thallus* with a distinct dorsoventral differentiation. The lobes are formed by the equal division of each branch at its terminus, a type of branching known as *dichotomy*. This tends to spread the thallus over the surface. It may assume the shape of a liver, and from this, and from a supposed function in relieving liver troubles, the liverworts received their name. Like the majority of liverworts it is found only on damp soil.

The species described is *Marchantia domingensis* from Nebraska.

The Gametophyte.—*External Structure.*—The lobes are broad and fleshy. Down the center of each extends a midrib, marked by a slight groove on the dorsal surface, and a thickened rib on the ventral surface. The lobes are thus somewhat bilateral.

Fine green lines divide the dorsal surface into rhombic areas which correspond with air chambers in the tissue beneath. In the center of each area is a small opening, the air pore.

The ventral surface has rhizoids which attach the thallus to the soil. There are two types: the anchoring rhizoids with smooth walls, and the peg rhizoids which have conical thickenings extending into the cell cavities. These are concentrated in the region of the midrib.

On the ventral surface, also, there are thin scales made of tissue one cell thick.

Internal Structure.—The space between the dorsal and ventral epidermis has also a dorsoventral differentiation. On the dorsal side are the air chambers which correspond with the rhombic areas on the surface. On the floor of the air chambers are short, branching filaments which grow into the air spaces. These contain large numbers of chloroplasts. A few chloroplasts may be found scattered in the roof and sides of the air chambers also.

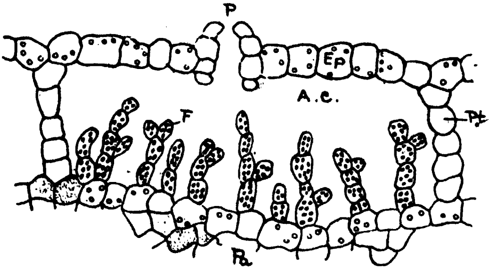


Fig. 170.—*Marchantia domingensis.* Section through air chamber of thallus. *A.C.*, Air chamber; *P*, air pore; *Pt*, partition between air chambers; *Pa*, parenchyma; *F*, filament containing chloroplasts.

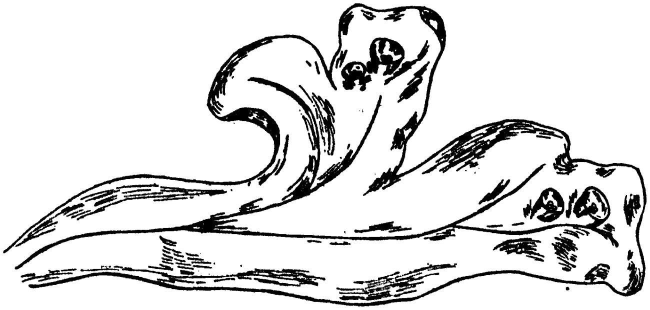


Fig. 171.—*Marchantia domingensis.* Thallus bearing gemma cups with gemmae. (Drawn by Muriel Hooper.)

Air chambers are the first adaptation in plants to the aerial life, and the chloroplasts are placed in the most advantageous position for access to air.

The air pores form short passageways from the dorsal epidermis to the air chambers. The cells which line the pores are in tiers, four cells to a tier.

Ventrally the space is filled with large parenchyma cells. These contain the storage and secreting tissue. Isolated cells for the formation of starch, oil, and mucilage, are found here and there.

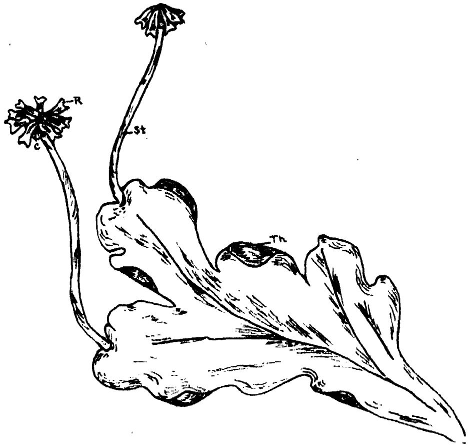


Fig. 172.—*Marchantia domingensis.* Thallus of female gametophyte bearing archegonial branches. *R*, Ray of archegonial disc; *C*, archegonial cushion: *St*, stalk; *Th*, thallus. (Drawn by Muriel Hooper.)

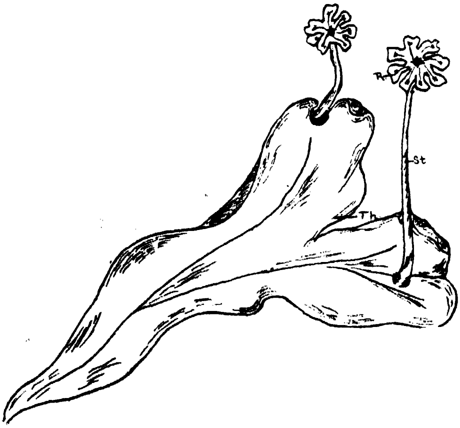


Fig. 173.—*Marchantia domingensis.* Male gametophyte bearing antheridial branches. *R*, Rays of antheridial disc; *St*, stalk; *Th*, thallus. (Drawn by Muriel Hooper.)

In the midrib are elongated cells which constitute a very rudimentary conducting tissue. They have thickened transverse ridges, and while no true vascular tissue is formed, the condition is suggestive of that found in the vascular plants. It is not found in the more primitive liverworts. No gametophyte tissue develops any more rigorous vegetative tissue than this. It remained for the sporophyte plant to establish the truly successful vegetative plant.

Asexual Reproduction.—Rapid multiplication of the gametophyte may be accomplished by the small cuplike growths on the dorsal surface, just over the midrib. These are the *gemma cups.* By the repeated divisions of a single epidermal cell in the gemma cup, a special stalked bud is formed, the *gemma.* The stalk is but one cell thick, and easily broken.

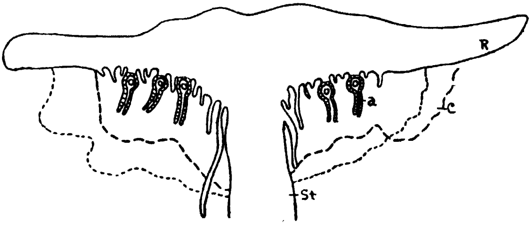


Fig. 174.—*Marchantia domingensis.* Section of archegonial disc. *a,* Archegonium; *c,* cushion; *R,* ray of disc; *St,* stalk.

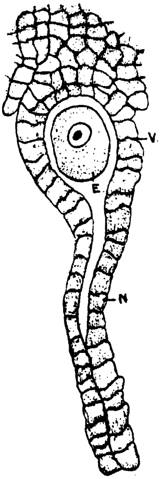


Fig. 175.—*Marchantia domingensis.* Mature archegonium growing down from the tissue of the thallus. *V,* Venter; *N,* neck; *E,* egg.

On the opposite edges of the distal surface of the gemma are two notches. The cells in these notches form the new thallus by division. This will not occur, however, unless the stalk be broken, so that the gemma falls to the ground.

Sex Organs.—The sex organs of the liverworts are typical of all the bryophytes and pteridophytes, and for this reason these two large groups have sometimes been classed as archegoniates.

The female organ is the archegonium, the male organ, the antheridium. These develop on umbrella-like receptacles which grow on erect stalks from the dorsal surface of the thallus. In *Marchantia domingensis* the stalks are relatively short, and the discs of the receptacles are lobed. The sex organs are formed in the lobes. Both the male and the female discs of Marchantia have eight lobes, but in the male of *Marchantia domingensis* these are very deeply margined so as to be almost fingerlike.

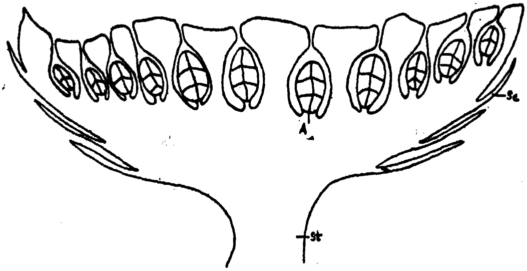


Fig. 176.—*Marchantia domingensis.* Section of antheridial disc. *A*, Antheridia; *St*, stalk of receptacle; *Sc*, scale.

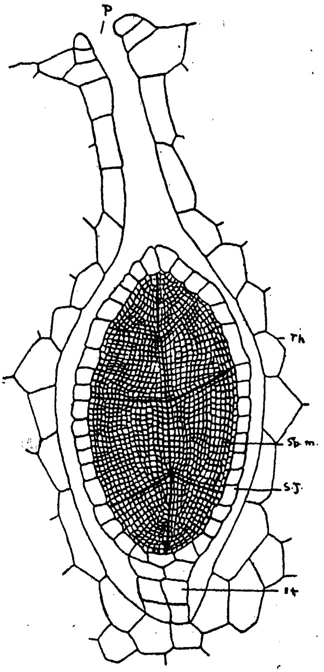


Fig. 177.—*Marchantia domingensis.* Antheridium embedded in tissues of the thallus. *P*, Pore; *Th*, thallus; *Sp.m.*, sperm mother cells; *S.J.*, sterile jacket; *St.*, stalk.

As Marchantia is a dioecious species, the organs are formed on separate plants. In monoecious species they develop on the same plant.

The Archegonium.—The archegonia grow down from the lower surface of the disc, and are protected by fringed outgrowths from the dorsal surface which curve down over the sex organs like an umbrella.

The archegonium is formed by the divisions of a single superficial initial cell, which forms an inner and an outer layer of cells. The outer layer forms an investing jacket of sterile cells, one cell thick. This consists of a venter, and a narrow neck.

The inner cells form an axial row of potentially fertile cells. Only the one cell in the venter develops into an egg, however, the eight cells in the neck becoming neck canal cells.

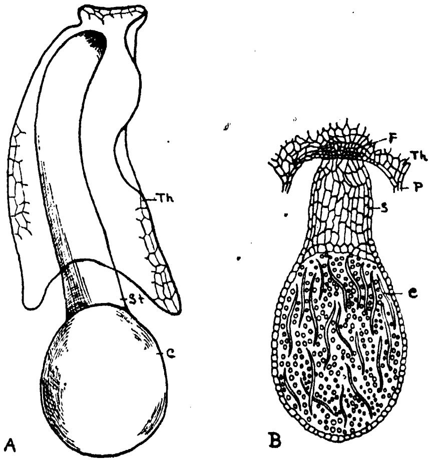


Fig. 178.—*Marchantia domingensis.* Sporophyte. *A*, Surface view. *B*, Section; *St*, stalk; *C*, capsule; *S*, spores; *e*, elaters. *F*, *foot.*

The Antheridium.—The antheridia develop in depressions on the dorsal surface of the male disc. A narrow canal leads into each depression, and the tissue in the depressions contains air chambers.

The antheridium is a stalked structure, arising, as does the archegonium from the divisions of a single cell. An outer layer of sterile cells forms an antheridial wall one cell thick. The inner cells continue to divide until hundreds of sperm mother cells are formed. Each one forms one spermatozoid, which becomes an elongate cell with the form of a spiral band. The band is slightly coiled, and has two long cilia attached near the anterior end.

At maturity a drop of water on the apex of the antheridium will cause the cells to disintegrate, and large masses of spermatozoids ooze out in a viscous liquid.

In general, the male and female plants are in close proximity, and secretions from the female plant undoubtedly assist in attracting the spermatozoids to the neck of an archegonium. As soon as they come in contact with the neck, the neck canal cells start to dissolve, thus forming a pathway to the egg. Normally, only one spermatozoid reaches the egg, and fertilization is accomplished by the union of the nuclei.

The Sporophyte.—The zygote formed by this union produces the sporophyte and development continues in the venter of the archegone, the cells of which divide and grow with the sporophyte, thus keeping it continually enclosed. Other tissues of the gametophyte also grow with the sporophyte so that three layers of tissues usually surround it.

The sporophyte develops into a plant with three regions: a foot, a stalk, and a capsule.

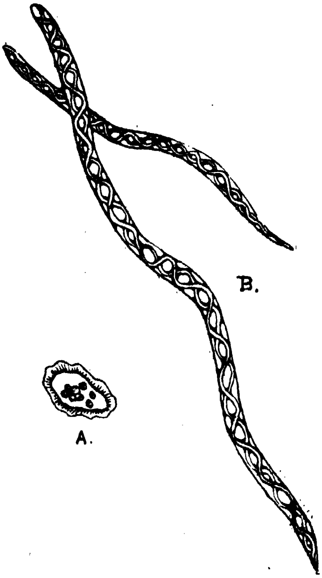


Fig. 179.—*Marchantia domingensis.* *A,* Spore. *B,* Elaters shed from sporophyte.

The foot is anchored to the gametophyte by a group of absorptive cells which grow into the gametophyte tissue. These cells absorb food from the gametophyte, and the sporophyte is, therefore, a parasite on the parent plant.

During development the stalk is very short, but upon maturity it elongates rapidly. At the terminus of the stalk is the capsule.

The capsule is a somewhat spherical organ, enclosed in a jacket of sterile cells one cell thick. The cells of the capsule develop two types of cells: the spore mother cells and the sterile elaters.

In the spore mother cells reduction takes place, reducing the chromosomes to the haploid number. During the process the spores are formed;

four to each spore mother cell, by two rapid divisions. As each spore of the tetrad is provided with a heavy wall, it can exist during unfavorable conditions.

The spores are disseminated by the activities of the elaters. These are long, slender cells, pointed at one end, and with spirally thickened walls. The cells are hygroscopic, curling up when dry and uncurling when moist. The alternation of these motions assist in liberating and scattering the spores.

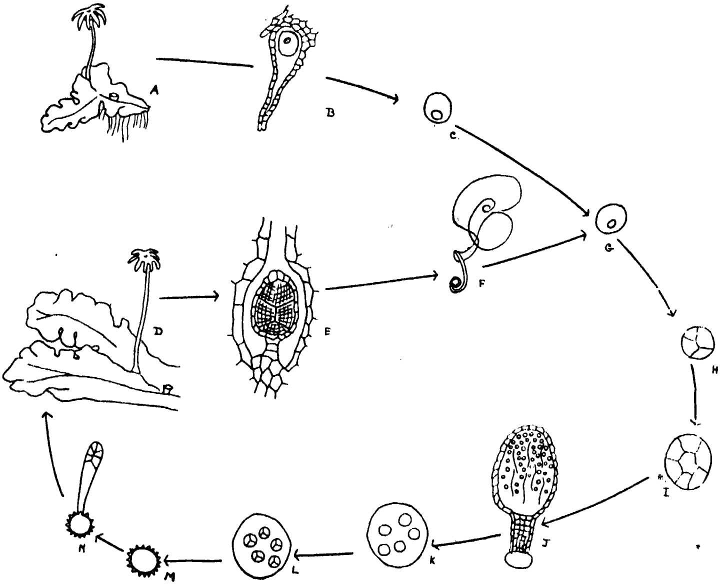


Fig. 180.—Diagrams to show the life cycle of Marchantia. *A,* Female gametophyte bearing archegonial branch and a gemma cup; *B,* an archegonium enlarged; *C,* egg; *D,* male gametophyte bearing an antheridial branch and a gemma cup; *E,* an antheridium enlarged; *F,* a sperm; *G,* the fertilized egg; *H* and *I,* stages in the development of the sporophyte; *J,* sporophyte; *K,* spore mother cells enlarged; *L,* tetrads; *M,* mature spore; *N,* germination of spore to form gametophyte.

LEAFY THALLUS TYPE

Polytrichum

Polytrichum is one of the true mosses, all of which are remarkably similar in structure. They have stems and leaves which resemble externally those of the vascular plants, but which are of a fundamental simplicity of structure. The vegetative structure is still a thallus, therefore, though approaching more closely than the liverworts to the advanced type of organization.

Mosses are a very familiar form of vegetation to those who walk in the woods, for they form thick carpets over the ground, over rocks, and often on the sides of trees; they are often called the carpet plants.

The Gametophyte.—The gametophyte is still the independent plant. It develops as a *protonema* of fine green filaments which branches freely along the surface of the earth much in the manner of some green algae. Some of the branches grow down into the earth, forming *rhizoids,* which anchor the plant to the soil. These lose their chlorophyll and become brown.

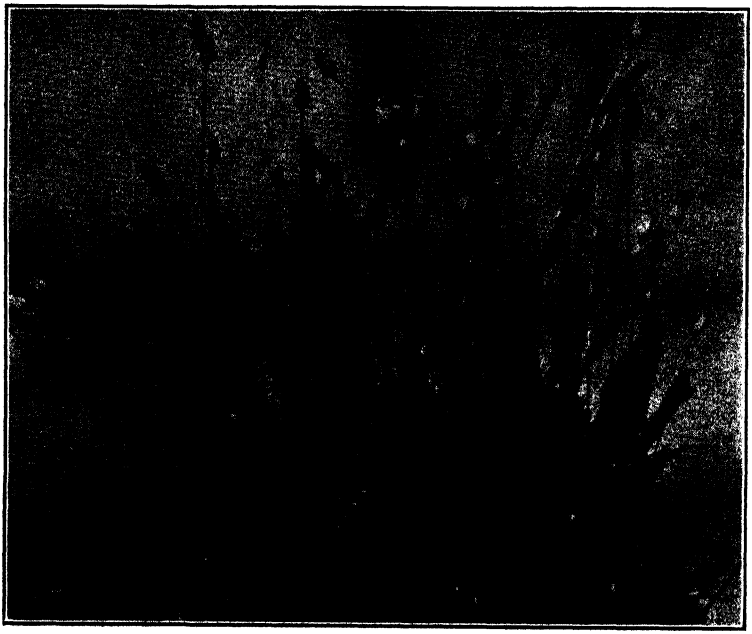


Fig. 181.—Polytrichum. Male and female plants, and mature sporophytes showing capsules. (Photograph by author.)

Any green cell of the protonema may produce a *bud,* though usually it is the basal cell of a branch. A small protrusion of cells is cut off from the protonema by a transverse layer of cells. An apical cell and one or two stalk cells are then differentiated.

The apical cell of the bud has the shape of an inverted pyramid, the base facing upward, and the three lateral faces having oblique slopes.

The bud develops into a *gametophore.* Growth proceeds by the production of three lateral segments, one from each of the oblique faces of the pyramid. The first division of the segment forms a longitudinal wall, dividing it into upper and lower cells. The upper cells give rise to the axial stem of the gametophore, and the lower cells to the leaves. Three rows of leaves develop, one from each lateral face.

The Gametophore.—The gametophore consists of *stem, leaves,* and *rhizoids.*

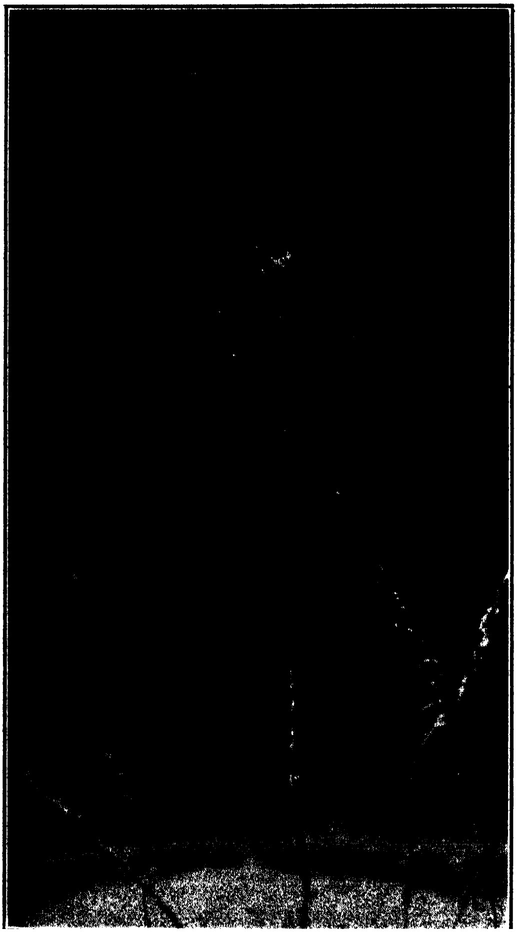


Fig. 182.—Polytrichum. Detail of male and female plants from previous figure. (Photograph by author.)

The stem is a central axial strand of simple structure, retaining the three-sided apical cell always at its terminus. The cells toward the periphery contain the chloroplasts. No vessels or sieve tubes are present as in vascular plants, but there are elongated cells which serve to conduct water and salts to the top of the stem. These are devoid of protoplasm and have transverse thickened bands. They occur also in the midribs of the leaves.

The leaves are small and spirally arranged around the stem, so close as to overlap one another. They are flat, leaflike structures, but only one cell thick except toward the center where the cell layers increase to form a midrib. The central cells of the midrib elongate to form conducting tissue like that in the stem.

Sex Organs.—Polytrichum is a dioecious plant, the archegonia developing on female plants, and the antheridia on male plants. Plants of both sexes are usually found growing in close proximity.

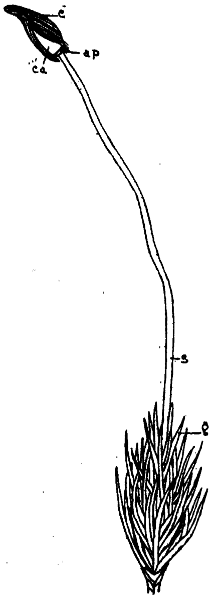


Fig. 183.—Polytrichum. Sporophyte attached to the gametophore. *C,* Calyptra; *ca,* capsule; *ap,* apophysis; *s,* stalk; *g,* gametophore.

The organs develop in groups at the apices of the gametophore stems, and usually arise from the three-sided apical cell.

The female plant often cannot be distinguished from the sterile ones, but the male plant develops a conspicuous inflorescence with a reddish disc in the center of a rosette of green leaves. The plant is about one centimeter high.

The Archegonium.—The archegonium has a short, massive stalk, an enlarged venter, and a long neck. There is a jacket of sterile cells, an egg in the venter, and a row of neck canal cells. At maturity these disintegrate and form a mucilaginous mass through which the spermatozoid reaches the egg.

The Antheridium.—The antheridia form in groups. Each one consists of a short stalk and a slender body surrounded by a sterile jacket. The cells of the jacket are green when young.

As growth of the branch may continue after the antheridium has developed, the apical cell has not contributed to its growth.

The cells of the body are the sperm mother cells, each one of which develops into one spermatozoid, with two long cilia.

Among the sperm mother cells are fine sterile hairs, the paraphyses.

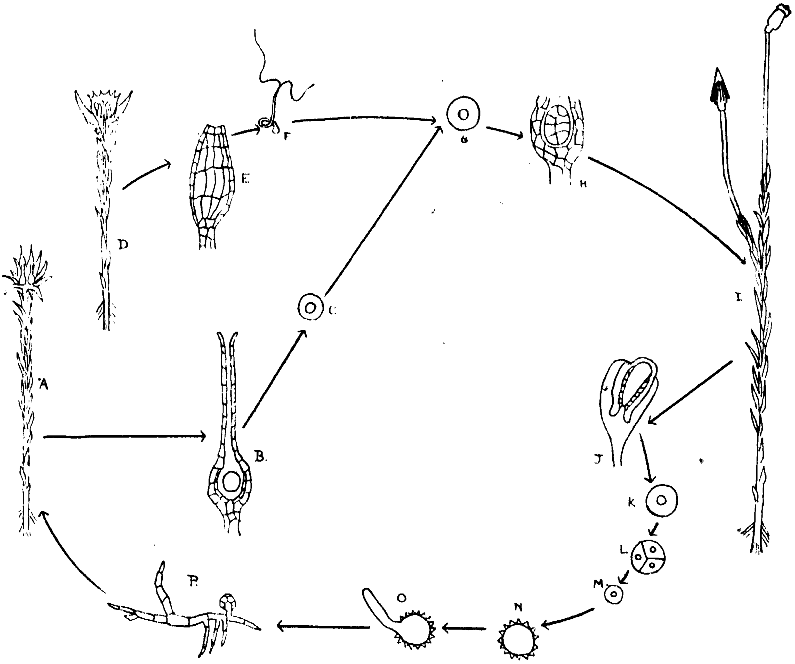


Fig. 184.—Diagrams to show the life cycle of a moss, Polytrichum. *A*, Female gametophore, bearing archegonia; *B*, an archegonium enlarged; *C*, a mature egg; *D*, a male gametophore, bearing antheridia; *E*, an antheridium enlarged; *F*, a mature sperm; *G*, the fertilized egg; *H*, a developing sporophyte; *I*, mature sporophyte on the gametophore; *J*, mature sporophyte enlarged; *K*, *L*, and *M*, stages in the development of a spore; *N*, a spore; *O*, a germinating spore; *P*, a protonema which forms the gametophore.

On maturity the cells at the apex spring apart, and the entire mass is extruded at one time. The cells then close again, leaving an empty antheridium.

Fertilization can only occur if there is moisture, and since the sex organs of mosses are aerial structures, it is probable that the splashing of raindrops during a shower is essential to bring the spermatozoid to the neck of the female organ. When in proximity, however, chemical secretions from the archegonium attract the sperm.

The Sporophyte.—The zygote develops into a long, slender embryo. The lower end of the embryo grows down through the tissues of the stalk into the stem of the gametophore, digesting the tissues as it grows. This forms the absorptive *foot* of the sporophyte.

The other end of the embryo grows upward. At first the wall of the venter grows with it, but the rate of growth in the embryo finally exceeds that in the venter, and it breaks through, carrying the tip of the archegonial tissue before it as a lid over the venter. The growth is rapid and a long, slender *stalk* is formed.

The Capsule.—The capsule in all true mosses is a complex structure. The lid carried forward during its development forms the *calyptra.* In Polytrichum this is large, and is covered with a dense growth of hairs. It is shed before the spores ripen.

The central tissue of the capsule is the *columella.* It is filled with storage and conducting cells, and contains a few chloroplasts.

The columella is surrounded by a cylinder of *spore mother cells,* each of which, by a process involving reduction, forms four spores. The fertile tissue does not extend the entire length of the capsule.

An outer cylinder surrounds the sporogenous tissue. This contains a layer of nutritive cells bearing chloroplasts, and is called the *tapetal layer.* At the lower end there is a single layer of epidermal cells containing a few stomata. In Polytrichum both the inner and outer cylinders contain air spaces.

The cells between the end of the stalk and the columella form a swollen mass of tissue, the *apophysis.*

At the tip, the sterile cells of the columella form a mass which fills the opening, over which an *operculum* projects like a lid. Two rings of tissue form about this mass of cells. The upper one is the *annulus,* the lower one the rim.

The operculum drops off when the spores are ripe, but directly under it lies a specialized tissue, the *peristome,* which prevents the apex from opening even when the lid has dropped off. The tissues of the peristome are bundles of fibrous cells forming crescents with their tips pointing up. The tips are united to those next adjacent, and resemble a row of teeth.

The teeth are hygroscopic. In wet weather they bend inward; in dry weather they bend out. Thus the spores are set free only when the atmosphere is dry enough to insure their dissemination by the wind.

The spore produces the *protonema* which is a developing gametophyte.

AFFINITIES OF THE BRYOPHYTES

The liverworts are the primitive group, and through them the aerial habit was established. A progressive development of the sporophyte took place within the group. In Anthoceros, the hornwort, the sporophyte has a sterile axis, and the fertile tissue is broken up into groups suggesting the beginnings of sporangia. In addition, some chlorophyll develops in the cells just beneath the epidermis, and stomata are found in the epidermis connecting with these areas. Thus the sporophyte is not wholly dependent, and shows a tendency toward the independence which is gained in the pteridophytes.

The mosses mark the culmination of a line which develops from the flat thallus type and assumes a leafy aspect with erect branches. There is a progressive sterilization of fertile tissue in the sporophyte which is raised into the air and develops a complex structure, provided with special structures to insure aerial dissemination of the spores. Although the gametes are also developed on leafy branches, they are dependent upon water for fertilization and swimming sperms are retained.

CHAPTER XXI

VASCULAR ORGANIZATION

SPORE-BEARING TYPE

The pteridophytes are the spore-bearing vascular plants. The group includes the club mosses *(Lycopodiales)*, the horsetails *(Equisetales)*, and the true ferns *(Filicales)*.

True vascular tissue is established with the development of a stele. The most primitive type is the *protostele* in which a mass of phloëm cells surrounds a single central shaft of xylem. There is primitively no endodermis, but the stele is surrounded by a cortex and epidermis. This condition is found in a group of early vascular plants of most primitive structure, the *Psilophytales*. They are found in the Devonian rocks of the early Paleozoic Age.

Similar steles are found in the *Lycopodiales* and in the sporelings of all pteridophytes. All stages in the development of the stele can be found among the *Filicales*. These are shown in Fig. 186.

Development of the Stele

In its development from the primitive protostele, the changing relations of the phloëm and xylem are such as to bring about a closer contact between the conducting tissues and the storage cells of the cortex. A further development which permits greater expansion of the stem is the arrangement of the protoxylem. Protoxylem is the first xylem to develop. If it develops in the midst of the xylem area without touching the phloëm, it is called *mesarch*. This type allows of no expansion. If the protoxylem develops on the side closest to the phloëm, it is *exarch*. It permits of growth toward the center. If it is laid down on the side farthest from the phloëm, it is *endarch*. This permits of growth outward and is the most successful type, since it permits increase in girth.

The stages in the development of the stele are the *protostele*, the *siphonostele*, and the *polystele*.

The Protostele.—The protostele in *Gleichenia pubescens* develops from a single procambium strand and is surrounded by an endodermis. In this respect, it is further advanced than the Psilophytales, but it still has no arrangement for contact with the cortex.

The Siphonostele.—The siphonostele is a hollow cylinder surrounding a central shaft of ground meristem, the pith. An endodermis separates the cylinder from the cortex. By this arrangement, bast and wood fibers are distributed in a hollow cylinder where their strengthening functions will do the most good.

Fig. 185.—The Christmas fern, Polystichum. (Photograph by M. C. Dickerson. Courtesy of the American Museum of Natural History.)

The phloëm may be laid down both inside and outside the xylem, in which case it is *amphiphloic.* The protoxylem is necessarily mesarch and no expansion is possible. It is the type found in *Adiantum pedatum.*

If the phloëm is laid down only on the outside of the xylem, it is *ectophloic.* In that case, it may be either endarch or exarch. Some species of *Osmunda* have the endarch ectophloic type. It is the type found in the adult stems of all angiosperms, while the roots retain the exarch habit and do not expand.

The Polystele.—The polystele is a further development of the amphiphloic siphonostele. The vascular tissue has been broken to allow for the leaf traces, and the phloëm has subsequently grown around the fragments of the cylinder. These have then overlapped and the endodermis has grown around each separate bundle. This type is found in *Pteris aquilina.*

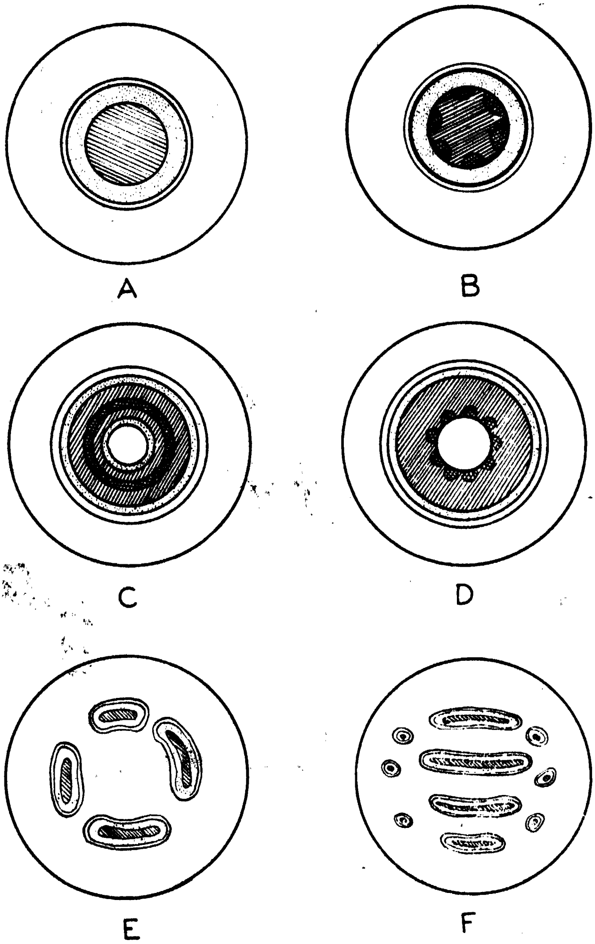


Fig. 186.—Development of the stele, diagrammatic. Xylem barred, protoxylem cross barred, phloëm stippled, endodermis plain. *A,* Protostele; *B,* exarch protostele; *C,* amphiphloic siphonostele, mesarch; *D,* ectophloic siphonostele, endarch; *E-F,* stages in the development of polystele.

Ferns

Among the attractive growths of the vascular plants are the ferns with their showy green rosettes. These are often seen in the open woods, or growing from crevices in the sides of inaccessible cliffs, but in the damp, shady places, they thrive most abundantly, and in the tropics their growth is often luxuriant.

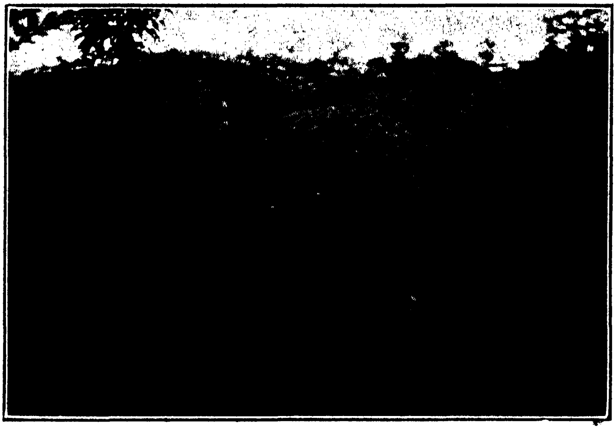


Fig. 187.—Tree ferns on roadside near Garoet, Java. (Photograph by author.)

In the majority of ferns today, the leafy rosettes rise directly from an underground stem, but their vascular tissue is capable of very great strength, for in the tree ferns the stems are erect and rise to as great a height as fourteen feet in some tropical regions. Indeed, in the days of their dominance the fossil relatives of the ferns are said to have reached a height of over a hundred feet. Fern leaves, also, may reach a length of from ten to fourteen feet in favorable climates, so that the lowly plants of the temperate regions give little idea of the possibilities inherent in even the most primitive of the vascular plants.

The true ferns of the Polypodiaceae differ in only such minor points of structure as to warrant a single description. Pteris, Polypodium, and Aspidium may be used as types. These are common brake and wood ferns which are easily obtained in most of the north temperate woods.

The Sporophyte.—The leafy plant is the sporophyte generation, and, while the gametophyte is still an independent plant, the tissues of the sporophyte best illustrate the true vascular structure.

Stem.—In the majority of ferns the stem is underground and creeping. In Polypodium, the stem grows parallel to the earth's surface; in Aspidium it may ascend obliquely over rocks though still largely underground; while in the tree ferns the stem grows erect, and the leaves radiate out from the top of the stem.

The stem of the fern is a *rhizome*. Growth occurs at the apex which is usually covered with minute epidermal hairs. The apical cell of creeping stems is usually wedge-shaped, but in Aspidium it may assume the three-sided pyramid characteristic of erect stems.

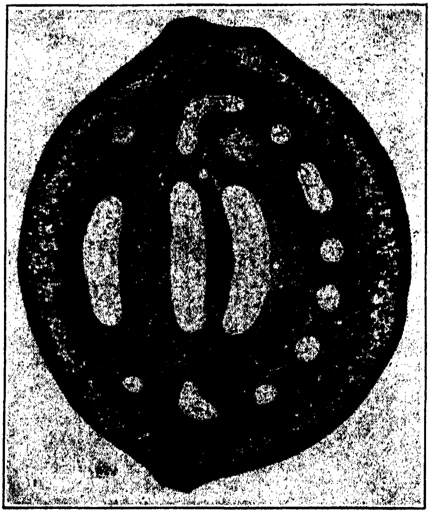


Fig. 188.—Pteris. Cross-section of rhizome showing the arrangement of the vascular bundles in the type known as a polystele.

The tissues of the fern stem are typical of vascular structure. There is an *epidermis, cortex,* and *stele.* In Pteris the stele is of the polystele type, with separate overlapping vascular bundles. The phloëm cells completely surround the xylem, and there is a layer of endodermis around each bundle. There is no cambium tissue.

The epidermis is a layer of thick-walled cells, beneath which are the cells of the cortex. Some cells of the stele are lignified, a process by which a woody structure is formed. This lends support to the stem.

The parenchyma cells of the cortex and pith serve as storage tissues.

The stem may have lateral branches, leaf stalks, and roots. In Aspidium the stem is entirely covered with leaf bases, and the roots of the adult arise almost wholly from the leaf stalks. In the young plant, however, they grow from the stem.

Root.—The roots also resemble the corresponding tissues of seed plants, both in manner of origin and in their general structure. The main root may branch off side roots, and short root hairs develop just distal to the region of the growing tip which is covered by a root cap.

Leaf.—Except in the tree ferns, the entire aerial structure is the leaf. The *stalk* is a modified petiole, thickened at the base where it leaves the ground, and prolonged into a thin *rachis*.

From the sides of the rachis the leaflets arise laterally. These are the *pinnae* which may be more or less subdivided into *pinnules*. The veins of the leaf are forked.

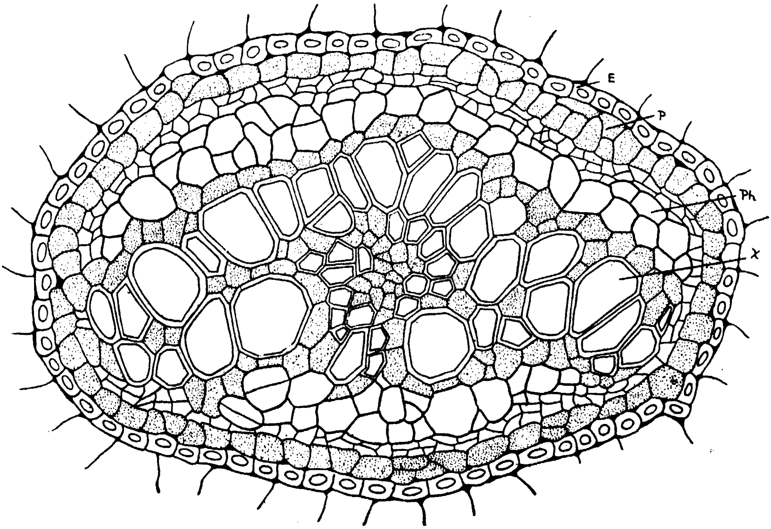


Fig. 189.—Vascular bundle of fern stem. *E*, Endodermis; *P*, pericycle; *Ph*, phloëm; *X*, xylem. (Drawn from a slide by Florence A. Basehoar.)

The young leaf is rolled into a coil so that it expands from the base upward. This is called *circinate vernation*.

The tissues of the leaf include an epidermis, and mesophyll tissue with vascular bundles. The mesophyll contains palisade cells and spongy tissue with intercellular air spaces. There are stomata on the lower epidermis.

The leaves of ferns may be of two kinds, the sterile vegetative leaves which are green and perform photosynthesis, and the fertile leaves which bear spores, and may or may not retain the green tissue. The fertile leaf is a sporophyll. In Polypodium every leaf is a sporophyll while in Aspidium the fertile leaves do not appear until fall, although they are also green.

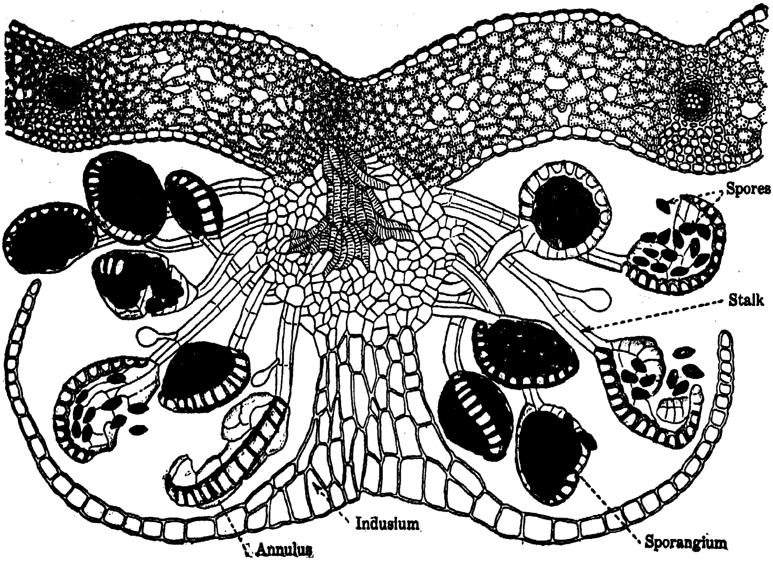


Fig. 190.—Polystichum (Christmas fern). Cross-section of leaf, through a sorus, showing different views of the sporangia. (Redrawn from Kny.) (Reprinted by permission from Textbook of General Botany, by Holman and Robbins. Published by John Wiley & Sons, Inc.)

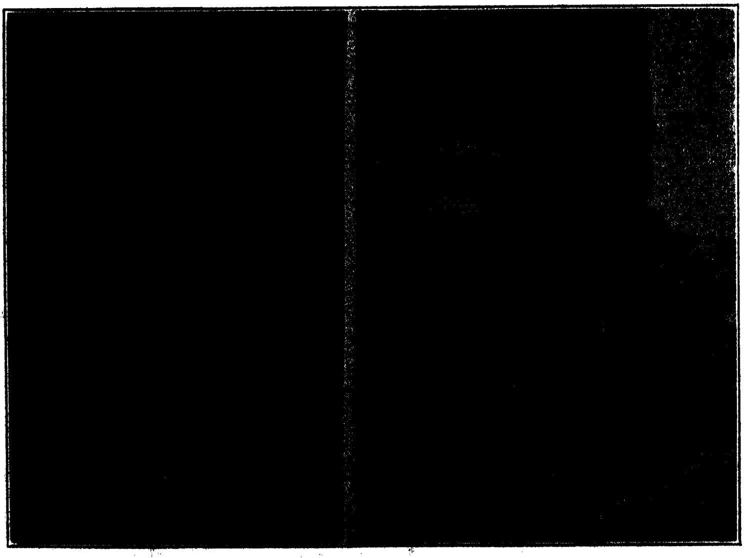


Fig. 191.—Fern leaves showing sori. *A, Dryopteris marginalis,* with indusium. *B, Polypodium vulgare,* without indusium. (Courtesy of the American Museum of Natural History.)

On the under surface of the sporophyll the *sori* are formed. Each sorus contains numerous *sporangia* which form the spores. In some ferns the sori are covered over by a thin tissue, the *indusium*. In Pteris this is formed by the folding in of the leaf margin; in Aspidium each sorus has a separate shield-shaped indusium, and in Polypodium the scattered sori are uncovered.

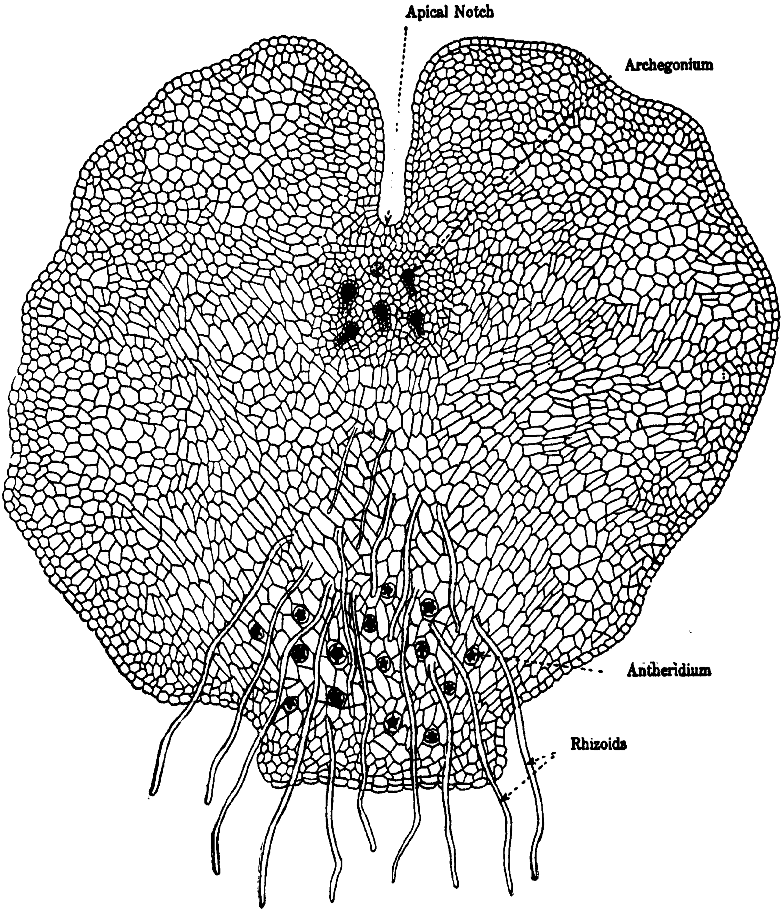


Fig. 192.—Mature gametophyte (prothallium) of fern, as seen from the ventral surface. (Reprinted by permission from Textbook of General Botany, by Holman and Robbins. Published by John Wiley & Sons, Inc.)

The sporangia are small, and each sporangium has a *stalk* and a *capsule*. Usually an *annulus* forms an incomplete ring about the capsule. The outer walls of the cells of the annulus are thinner than those of the inner walls, so that when dry, they contract like a spring, and thus release the spores. Between the end of the annulus and the stalk are typically a few thin-walled cells, the *lip cells,* and it is between these cells that the sporangium splits when the annulus contracts.

The Gametophyte.—The gametophyte is a relatively small and inconspicuous plant. It develops from a germinating spore after a period of rest, and is frequently found on the outside of flower pots, especially those in greenhouses where the atmosphere is moist.

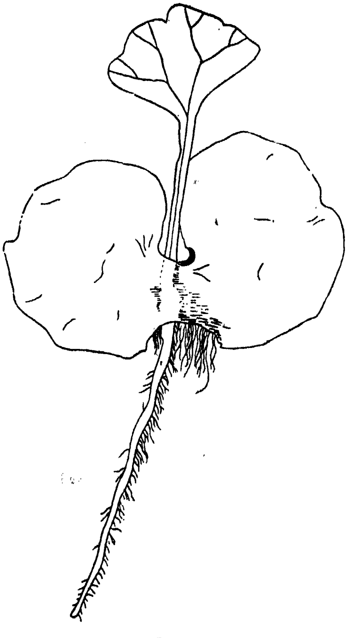


Fig. 193.—Fern. Sporophyte attached to gametophyte, showing primary root, and primary leaf.

The germinating spore develops a short green filament from which the tissues of a small heart-shaped plant are formed by repeated divisions of the apical cell. In the mature gametophyte the apical cell is at the base of the notch, and just back of this region the cells are several layers thick. The rest of the plant is only one cell thick, and minute one-celled ***rhizoids*** grow down from the ventral side. In general, therefore, the structure of the gametophyte is more nearly like that of the thallus in the bryophytes, and is called a *prothallium.*

On the under surface the sex organs are formed. As a rule the organs of both sexes are formed on one plant; the female organs just back of the notch, and the male organs in the region of the rhizoids near the margin of the plant.

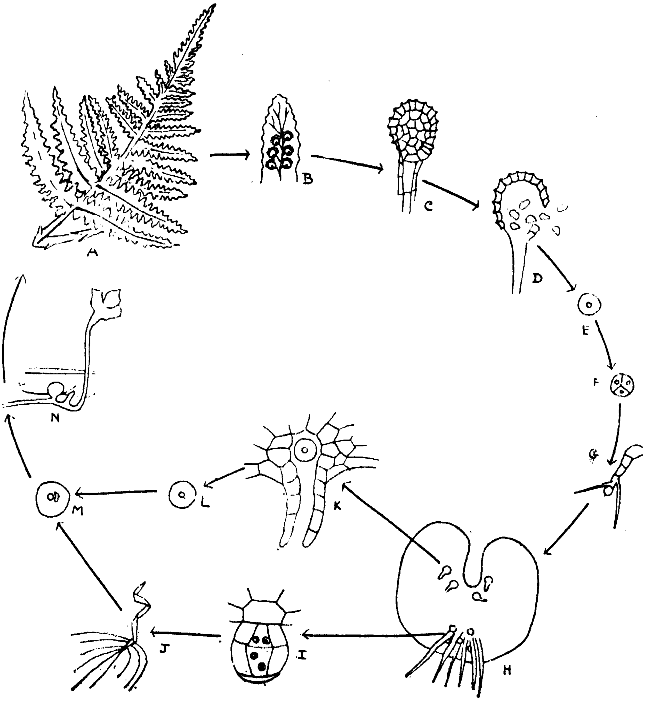


Fig. 194.—Diagram to show the life cycle of the fern (based on Aspidium). *A*, Leaf of sporophyte; *B*, fertile leaf, bearing sori; *C*, a sporangium; *D*, a ripe sporangium discharging spores; *E*, spore mother cell; *F*, tetrad of spores; *G*, stage in the development of the gametophyte; *H*, mature gametophyte; *K*, archegonium enlarged; *L*, mature egg; *I*, antheridium enlarged; *J*, mature sperm; *M*, the fertilized egg; *N*, a developing sporophyte.

The Archegonium.—The female organ is a short flask-shaped archegonium with the venter embedded in the tissue of the gametophyte. There is an egg cell in the venter and usually a single neck canal cell which fills the opening of the canal.

The cells of the archegonium secrete a weak solution of malic acid to which the sperm are very sensitive.

The Antheridium.—The antheridium is dome-shaped, and is not embedded in the tissue. It has a sterile jacket inside which by repeated division sperm mother cells are formed. Each sperm mother cell produces one spermatozoid which has the form of a spiral filament with a tuft of long cilia near one end.

Development.—After the sperm penetrate the neck canal, and one has successfully fertilized the egg, a wall is formed about the zygote, and division into four cells occurs at once. These form the primary growing points of the embryo, and each develops into one of the embryonic tissues as follows:

1. The foot which remains attached to the prothallium and absorbs food for the developing embryo.
2. The primary *root* which grows downward into the soil.
3. The primary *leaf* which develops *chloroplasts,* and so starts photosynthesis.
4. The *stem* which becomes the permanent *rhizome,* and from which the roots and leaves of the adult sporophyte develop.

The rhizome is the only one of the embryonic tissues which persists in the adult plant. As the tissues shrivel up, the gametophyte also withers, and the sporophyte becomes completely independent.

HETEROSPORY

Selaginella

Selaginella is one of the club mosses and is a small living representative of an ancient group of gigantic plants in which a condition of *heterospory* exists. Microspores and macrospores are borne on separate sporangia and on separate sporophylls. This condition and the consequent reduction of the fertile tissue approximates that of the seed-bearing plants. It signifies a further advance in sexual differentiation, pushing it back into the sporophyte generation so that separate male and female gametophytes may be formed. In the spermatophytes, these are so reduced as to be practically parasitic on the sporophyte plants.

The Sporophyte.—The sporophyte plants have creeping shoots with small triangular, nonpinnate leaves arranged in four longitudinal rows. Those on the terminal portions are the fertile branches, and these are divided into male and female regions. In some species the division is between base and tip; in others, between opposite sides. The fertile portion of the stem is called a *strobilus,* and near the base of the inner side of each leaf, or sporophyll, is a *sporangium.* The leaves are called macro- or microsporophylls according to the type of sporangium produced.

The microsporangium produces many microspores, usually sixty-four. In the macrosporangium only one cell functions. This cell divides forming a tetrad of spores all four of which become functional macrospores. All other cells of the macrosporangium are reduced to a vegetative function. This is typical of seed formation.

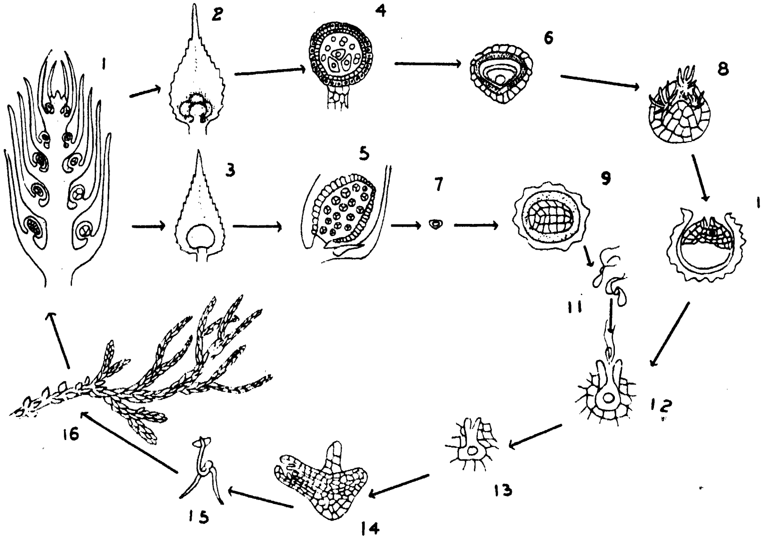
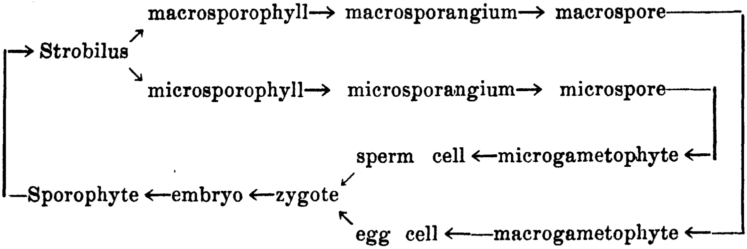


Fig. 195.—Life cycle of Selaginella. *1*, Strobilus, microsporophylls on left, macrosporophylls on right; *2*, macrosporophyll with four macrosporangia; *3*, microsporophyll; *4*, macrosporangium with a tetrad of spores; *5*, microsporangium with tetrads of spores; *6*, a macrospore; *7*, a microspore; *8*, macrogametophyle; *9*, section of a microgametophyte; *10*, section of a macrogametophyte showing archegonium; *11*, microgametes; *12*, microgamete *entering archegonium; 13*, zygote; *14*, developing embryo with apical cell ahead, young root above and root below; *15*, young sporophyte; *16*, sporophyte plant with terminal strobili.

The Gametophytes.—The gametophytes develop within the spore walls and are never free. The microgametophyte is completely parasitic, being reduced to a very few cells. The macrogametophyte protrudes very slightly from the sporangium during its development and produces a few chloroplasts, thus retaining a partial independence.

The microgametophyte may penetrate the macrosporangium before it is mature and continue its development there. Although no longer dependent upon water to bring the two gametes together, the sperm cells develop two long cilia on the spiral band.

The macrogametophyte remains within the macrosporangium during the early stages of development. This also is typical of seed formation. Experimentally, it has been found possible to keep the macrogametophytes of Selaginella within the macrosporangium throughout its entire development, thus completing the requisites of a true seed.


macrosporophyll→ macrosporangium→ macrospore
→ Strobilus
microsporophyll→ microsporangium→ microspore
sperm cell ←microgametophyte ←
—Sporophyte ←embryo ←zygote
egg cell ←—macrogametophyte ←

AFFINITIES OF THE PTERIDOPHYTES

It is not in the modern plants, but in the fossil fernlike growths of the Paleozoic Age that we must look for the ancestral pteridophytes, for the history of all the land plants is buried in antiquity. Among the plants which flourished in the Paleozoic Age were the forms which gave rise to the modern ferns, and to the spermatophytes as well.

The modern ferns are typically homosporous, and the fertile tissue is widely distributed. Homospory is probably a more primitive condition than heterospory, and a general tendency to restrict the fertile tissue shows throughout the group. In heterospory the direction of development is toward still further restriction of fertile tissue with increasing dependence of the gametophyte. There is a tendency toward seed development which points in the direction of the cones and flowers of the spermatophytes.

Although Selaginella cannot be considered to be directly ancestral to the spermatophytes, there is no doubt that the origin of the seed-bearing plants is to be found among the heterosporous pteridophytes.

CHAPTER XXII

VASCULAR ORGANIZATION (Cont'd)

SEED-BEARING TYPE

The spermatophytes are the seed-bearing plants. They represent the height of plant development, since with the production of seeds came the complete dependence of the gametophyte, and the strengthening of the vascular tissue of the sporophyte.

The strengthening of the vascular tissue has been accomplished by four progressive steps:

1. Separating the central shaft of procambium into separate strands allows the formation of medullary rays. These establish radial paths of conduction between the storage and conducting cells, thus facilitating contact with food and water.
2. Breaking of the ectophloic siphonostele into a ring of collateral bundles gives concentrated strength to the stem.
3. Production of a hollow cylinder or ring of permanent growth tissue, the cambium, provides for unlimited increase in girth.
4. The branching habit further aids in the success of the highest groups by increasing the foliage area for greater contact with the sun's rays.

The spermatophytes, consequently, show a multitude of variations and a complexity of structure not found in any of the lower plants. The perfection of the flower accompanies the final reduction of the gametophyte to a parasitic structure and establishes a protective envelope about the developing seed in which the gametophyte is enclosed.

There are two large groups of spermatophytes: the gymnosperms which are cone-bearing, and the angiosperms which are flower-bearing. The cone is a strobilus, and the macro- and microspores are borne on macro- and microsporangia as in Selaginella. The seed is formed on the surface of the macrosporophyll, and is thus partly exposed; hence the name, *gymnosperm.*

In the angiosperms, the seed is always enclosed within an ovary which is formed by the fusion of macrosporophylls, and surrounding the ovary are whorls of modified leaves, the *sepals* and the *petals*, which are often brilliantly colored. Together, these structures constitute the flower.

The gymnosperms are the more ancient group, and a few living genera of the extinct groups have persisted. The most successful of the type has been the conifers. These are the modern forms. They have developed one type of growth only, the tree or small woody plant with branches radiating from a central, circular trunk. The younger and shorter branches are always above the older, thus producing the cone-shaped tree characteristic of the evergreens when grown without interference from neighboring trees. The type is known as *excurrent*.

Fig. 196.—A gymnosperm. Spruce tree photographed to show the excurrent type of branching. (Photograph by author.)

The leaves perform photosynthesis throughout the year. They are needle-shaped, and thickly coated with a waterproof substance, called *cutin*. Both the excurrent growth and the thick, linear leaf are adapted to cold and semiarid regions, since they provide for a minimum of transpiration. Gymnosperms are found, therefore, in climates unsuited to any other type of growth, such as mountain tops, and will retain their greenness throughout the winter months when all the leaves of the angiosperms have withered and dropped off.

The angiosperms have developed two types of growth: the tree and the small herbaceous plant. The woody angiosperms approach more closely to the gymnosperm type. They develop shrubs or trees by *deliquescent* branching; the central stem dividing into smaller and smaller branches as it increases in height. This permits a lateral spread as well as elevation, and is most effective in exposing a large number of leaves to light.

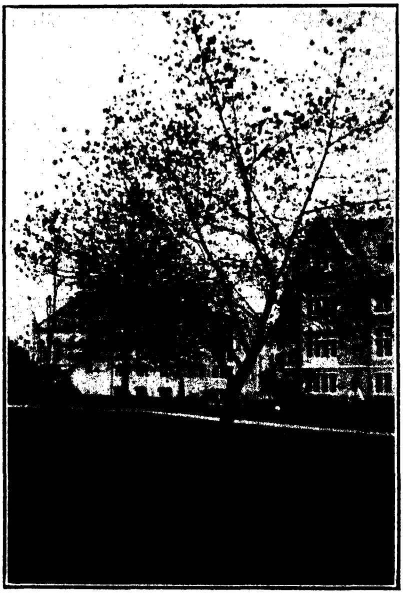


Fig. 197.—An angiosperm. A maple tree photographed in the early spring to show the deliquescent type of branching. (Photograph by author.)

The herbaceous type is a specialization of the vascular structure and is adapted to growth in temperate and semiarid regions where the water supply is not constant the year around, and where the alternation of seasons makes continued existence difficult. These plants have lost the habit of wood formation, and are soft-stemmed, gaining resistance through underground storage organs or seeds. Such plants may die at the end of the season, depending for their continued existence entirely upon the seed. This is the *annual* type, and many specializations are developed for insect pollination and the dispersal of the seeds. Other plants store food in underground organs, so that only the part above the ground dies. The stored food supplies nourishment for a new shoot which grows up a second year. These are *biennials.* Still others are of the *perennial* type, only the leaves of which die. Buds, with waterproof coverings, provide for the growth of new leaves the following season.

All woody angiosperms are perennials, and it is probable that the herbaceous type was developed from woody, perennial ancestors. The flowers of the herbaceous type show the highest specializations of the whole plant kingdom.

So many characteristic differences distinguish the gymnosperms from the angiosperms that these have been briefly outlined in a table. The comparison is made with the woody angiosperms mainly.

GYMNOSPERMS (conifer type)	ANGIOSPERMS
Plants woody	Plants woody or herbaceous
Plants xerophytic	Plants mesophytic (mainly)
Branching excurrent	Branching deliquescent
Wood contains tracheids, but no tracheal tubes	Wood contains both tracheids and tracheal tubes
Leaves typically evergreen	Leaves typically deciduous
Seeds in cones	Seeds in flowers
Seeds exposed	Seeds enclosed
Male gametophyte reduced to 6 cells	Male gametophyte reduced to 3 cells
Female gametophyte of many cells	Female gametophyte one 8-nucleate cell, an embryo sac
Archegonia produced	No archegonia produced
3 to 8 cotyledons	1 or 2 cotyledons
Endosperm a gametophyte (n)	Endosperm of sporophyte tissue (3n)

The details of spermatophyte structure have been completely covered in Part I. The discussion at this point, therefore, will be limited to the life cycle.

CONE-BEARING TYPE

Gymnosperms

The cone-bearing plants have had a separate history from the flower-bearing type, although a common origin from the Cycadofilicales is indicated.

PHYLOGENY

Cycadofilicales.—The Cycadofilicales are an extinct group with no living representatives. Extinct since the late Carboniferous Age, much of the detail of their structure is still unknown. They are called the *seed ferns,* but are classed as primitive Gymnosperms. Lyginodendron and Lyginopteris are among the best known genera.

Sporophyte.—The sporophyte plant is fernlike and profusely branching. The stele of the root has the typical radial arrangement and that of the stem is of the *amphiphloic siphonostele* type with much secondary wood.

The leaves are fernlike, and the resemblance of the microsporangia to those of the ferns is so striking as to indicate a close relationship. The macrosporangia form seeds, however, which relate the group definitely to the seed-bearing vascular plants.

Seed.—A seed is a mature sporangium within which the macrospore remains throughout its entire development. The spore forms within an ovule, the sporangium walls form the *integuments.*

The development of the seed is represented diagrammatically in Fig. 198. Lepidocarpon (A) represents one of the extinct heterosporous lycopods in which the macrosporangium was surrounded by an outgrowth from the sporophyll which resembles an integument. There is an opening at the terminus which resembles a micropyle. Only one macrospore attained full development, and the prothallus remained within the wall of the spore. There is no pollen chamber, so the microspores must have reached the parent plant before the macrospores were set free. Selaginella is the best living representative of the group. The condition is suggestive of seed development, and no doubt represents an initial step in that direction.

In the Cycadofilicales (B), the integuments are formed by the sporangium wall, but the *ovule* rests in a capsule of sporophyll tissue which is believed to be an outer integument. Of the two inner integuments the one next to the ovule was apparently fleshy, the outer one was stony.

The ovule contains a *nucellus* which is free at the tip. The integuments have grown up around the free end to form protective beaks around a pollen chamber. In several specimens microspores have been found in the pollen chamber, so there is no doubt of its function.

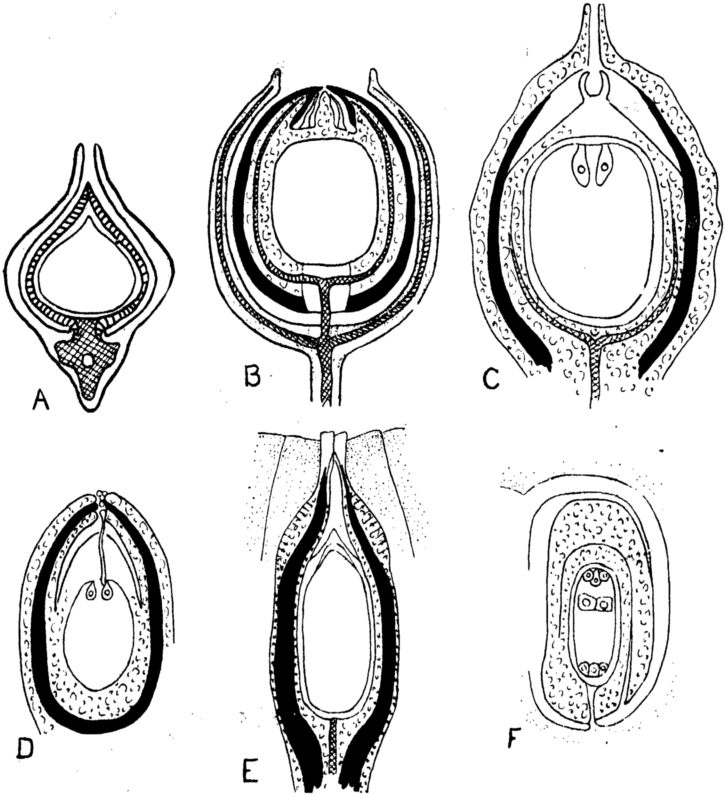


Fig. 198.—Stages in the development of the seed, diagrammatic. Vascular tissue cross hatched, inner and outer segments marked by half circles, central integument, usually stony, in black. Sporophyll tissue stippled. *A*, Lepidocarpon; *B*, Lyginodendron; *C*, Zamia; *D*, Pinus; *E*, Bennettites; *F*, Lilium. Note reduction of vascular tissue, the reduction of integuments, and the reduction of pollen sacs to form the micropyle.

The microspores are more like those of cycads than are those of the ferns, and are believed to have been swimming sperms. The archegonia formed in the ovule are elongated and, although no embryos have ever been found in the seeds, their development cannot be doubted.

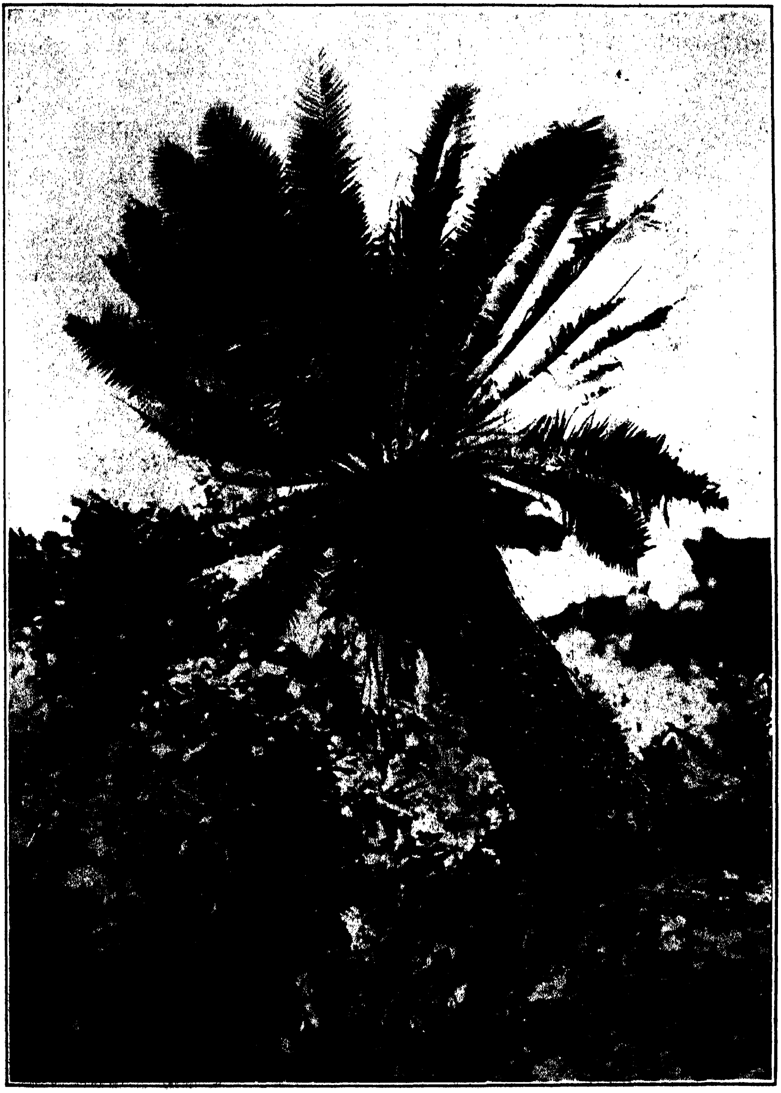


Fig. 199.—*Dioön edule*, a characteristic cycad from Chavarrillo, Mexico. Cycads of this size seldom stand straight. (After Chamberlain.)

This group is the recognized ancestral stem from which all the higher groups have been derived.

Cycadales.—The cycadales are cone-bearing with rosettes of leaves at the terminus of a massive stem. Leaflike sporophylls and swimming sperms mark their derivation from the

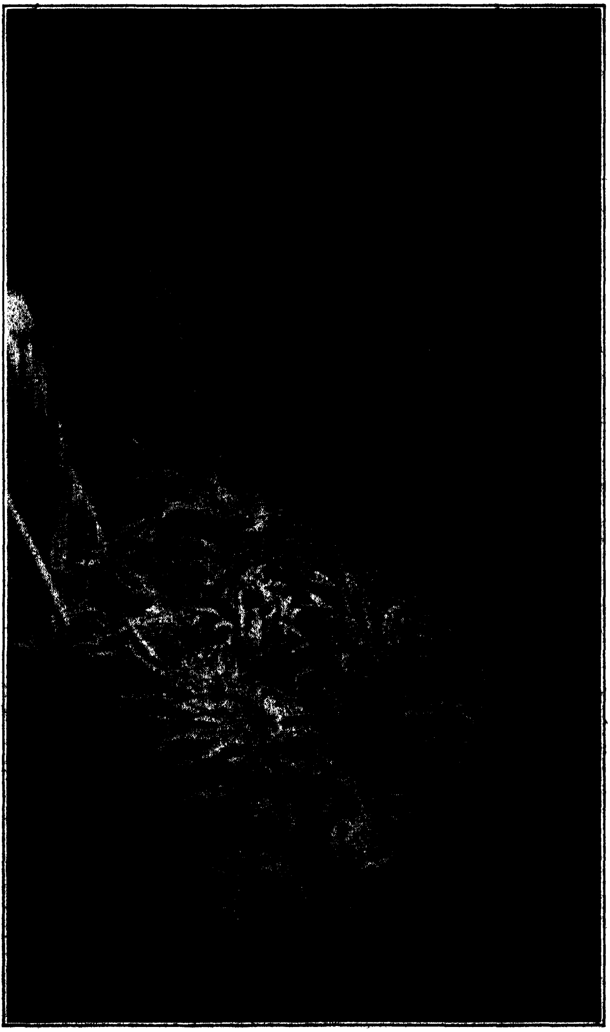


Fig. 200.—*Cycas revoluta* (sago palm) on the campus of St. John's University, Shanghai, China. Terminal cone on female plant. Note the leaflike sporophylls and the loose cone arrangement. This is an early stage in the compacting of the cone in cycads. (Photograph by W. M. Porterfield.)

cycadofilicales. They flourished during the Cretaceous period, although there are indications that they were differentiated from the earlier groups in the late Carboniferous period. A few genera have persisted to the present time. They are limited to tropical or subtropical regions.

The closing of the cone has been progressive throughout the group. The macrosporophyll develops in the center of the leafy rosette of the female plant. In the primitive types the macrosporophylls are leaflike and retain the pinnae on the sterile portions. They are arranged in a loose, open crown. In other types, the pinnae of the sporophylls are reduced to serrations and finally to more bractlike leaves which are grouped loosely into a cone formation. In Zamia is seen the final reduction of the bract and the compacting of the cone.

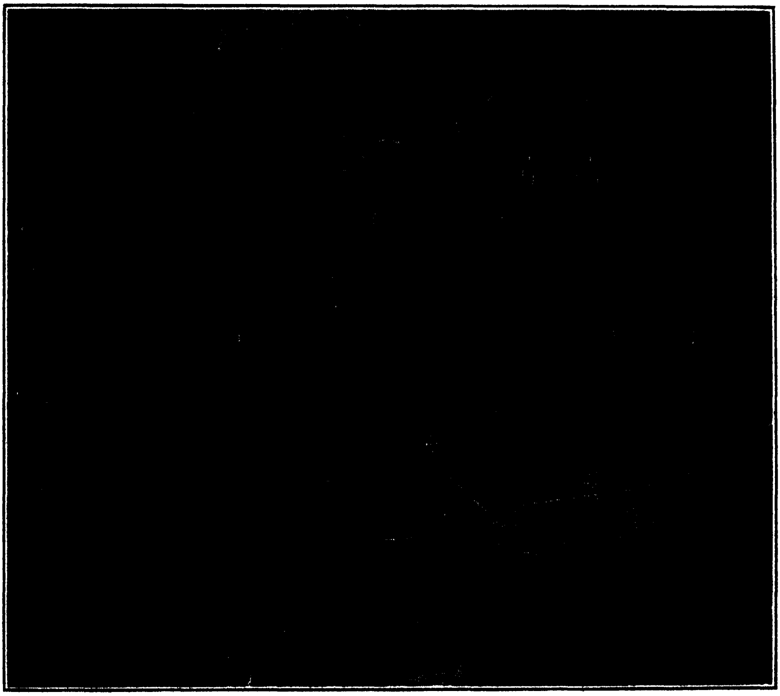


Fig. 201.—*Zamia integrifolia* in the pine woods on the Everglade Keys, Florida. Female plant with pistillate cones in center; male plant with staminate cones at extreme right. The sporophylls are reduced to bracts which are closely compacted into cones. The final stage in the compacting of cone in cycads. (Photograph by John K. Small.)

Bennettitales.—The Bennettitales (Fig. 203) are of interest because of their possible relation to the ancestral angiosperms. They were cycads which reached their climax in the Jurassic period and became extinct in the Cretaceous period. The leaves are typically cycad structures, but the strobili are of a distinct type. They were borne near the top of the plant in large numbers in the axils of the leaves. The microsporophylls are leaflike and are grouped around a cone of macrosporophylls, each of which bears a single terminal ovule.

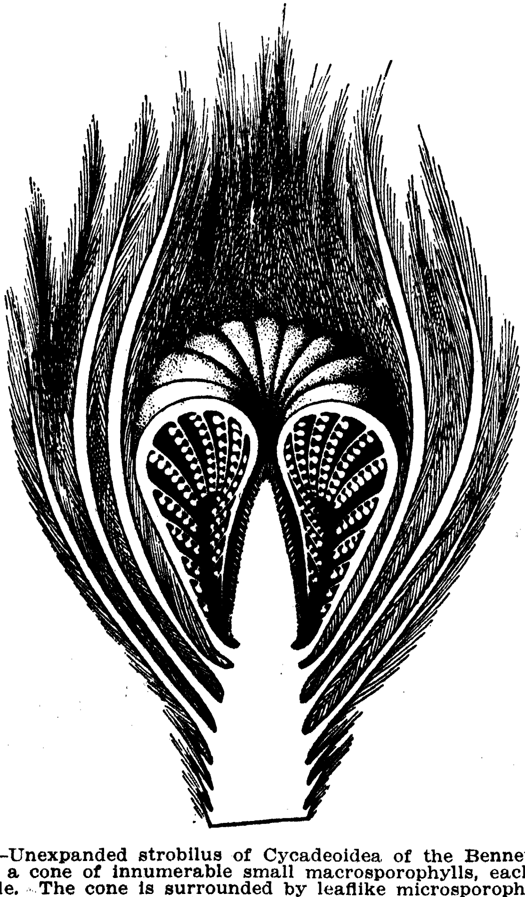


Fig. 202.—Unexpanded strobilus of Cycadeoidea of the Bennettitales. In the center is a cone of innumerable small macrosporophylls, each bearing a terminal ovule. The cone is surrounded by leaflike microsporophylls outside of which are bracts. (After Wieland.) (From Charles J. Chamberlain, Gymnosperms: Structure and Evolution. Reprinted by permission of the University of Chicago Press.)

There are no lateral pinnae, the stem of the ovule resembling a peduncle. Among the macrosporophylls are numerous sterile leaves. The arrangement of the macrosporophylls on the axis of the peduncle is of the spiral type, typical of the cone, and points to a possible relation to the more primitive groups of the angiosperms which still retain the spiral arrangement.

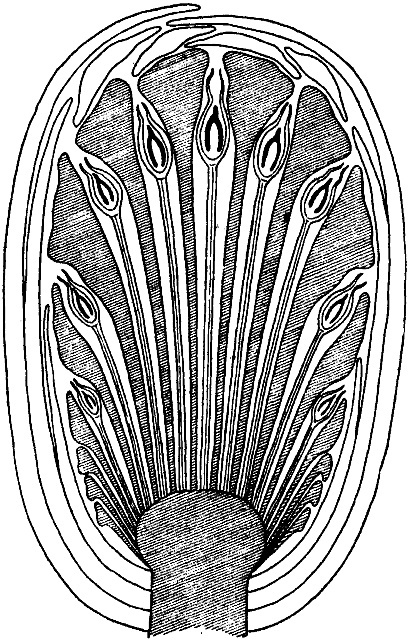


Fig. 203.—Female strobilus of *Bennettites gibsonianus* showing terminal seeds with dicotyl embryos. Note the long, slender macrosporophylls alternating with sterile bracts. Modified by Scott after Solms-Laubach and Potonie. (From Charles J. Chamberlain, Gymnosperms: Structure and Evolution. Reprinted by permission of the University of Chicago Press.)

There are three integuments, of which the central layer is believed to have been stony. The outer layer has striations in the thickened upper portion, and the inner layer was probably membranous. The integuments form beaks around a pollen chamber which is typical of the cycads.

Ginkgoales.—The Ginkgoales are an ancient group. Leaves of the order have been found in the late Paleozoic era. Except for a single genus, Ginkgo, they have been extinct since the

Jurassic period. Ginkgo is known as the **maidenhair tree** because of the resemblance of its leaves to those of Adiantum, the maidenhair fern. It is a veritable living fossil.

The treelike growth and profuse branching are more like that of the conifers than of the cycads, and the stems show even more direct relationship in the small pith and cortex, and the increase in secondary wood with definite annual rings. The structure of the stele is an endarch siphonostele, a condition which persists throughout the conifers.

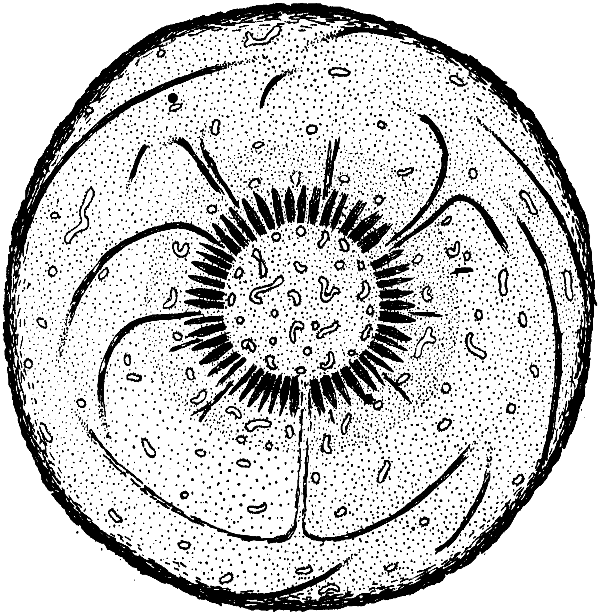


Fig. 204.—Stem of a cycad, *Zamia floridana.* Transverse section showing endarch siphonostele in adult stem, with large pith and cortex and scanty zone of wood. Parts of leaf traces are also shown. (From Charles J. Chamberlain, Gymnosperms: Structure and Evolution. Reprinted by permission of the University of Chicago Press.)

The macrosporophylls are borne on bilobed spurs with minute leaves.

Coniferales.—In the conifers the most primitive cones are fully compact. These are the familiar evergreen trees with the excurrent branching. They are largely xerophytic and are adapted to colder climates than are the flower-bearing plants.

The Pine

The familiar pine tree is the sporophyte. It resembles the other evergreens (firs, hemlocks, cedars, and spruces) in general structure, but differs from them in the arrangement of the needles. These are grouped in clusters of from two to five, and are surrounded at the base by a whorl of scales.

Fig. 205.—Australian black pine. Cluster showing carpellate cones. The early spring cones are at the tip of the branches, and the one-year cones at the base. (Photograph by author.)

Male and female cones are produced on the same tree. The female cone is called the carpellate (pistillate) cone, or the macrosporangiate strobilus; the male cone, the staminate, or microsporangiate strobilus. On these strobili, the macro- and microsporophylls are grouped spirally about a central axis. The carpellate cones are the familiar pine cones, and are much larger than the staminate cones. They remain on the tree for two years. The staminate cones appear in the early spring in terminal clusters on some of the branches. The cones develop on the clusters laterally. At the end of a few weeks these shed the pollen and drop to the ground.

Fig. 206.—Detail of the one-year carpellate cones. (Photograph by author.)

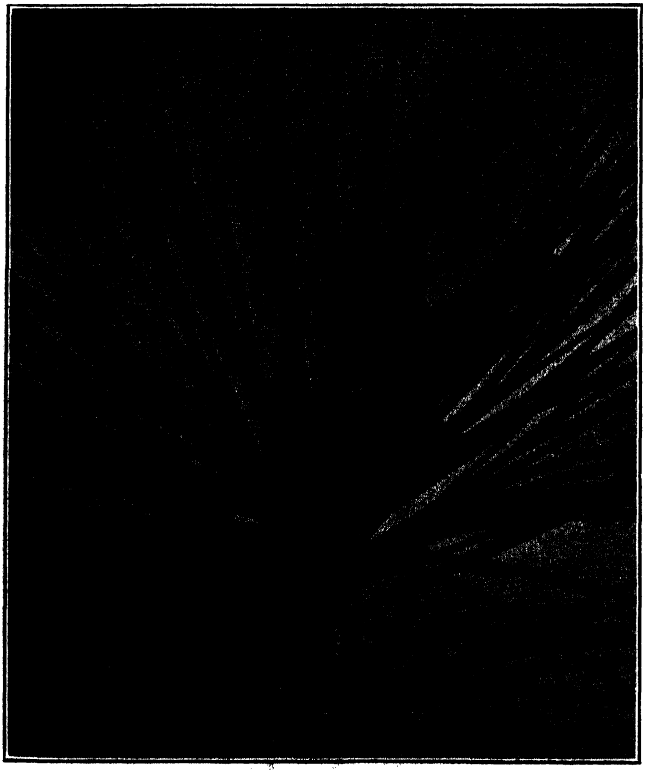


Fig. 207.—Australian black pine. Cluster showing young staminate cones. (Photograph by author.)

The life history of the pine occupies the greater part of two years. In the spring of the first year the pollen grains are formed and scattered widely by the wind. The few which come in the vicinity of the carpellate cones are sifted through the openings between the sporophylls and come to lie close to the opening of the micropyle. A swelling of the tissue about the micropyle serves to imprison some of the pollen grains, and in the course of the following year a *pollen tube* will reach the ovule.

Fig. 208.—Australian black pine. Staminate cones after discharging microspores. Photograph taken one week later than previous figure. (Photograph by author.)

At the time of pollination, the macrosporangium (ovule) consists of a mass of tissue, the *nucellus,* and integuments. In the nucellus tissue the macrospore mother cell produces twenty-four macrospores. Only one of these remains to produce the macrogametophyte tissue in which the archegonia develop. The process takes a year. When the pollen tube completes its slow growth into the nucellus, the egg is mature in the archegonium, and union of the nuclei takes place to form the zygote.

Immediate development then takes place and a proembryo is formed. Late in the second year the mature seed drops from the tree.

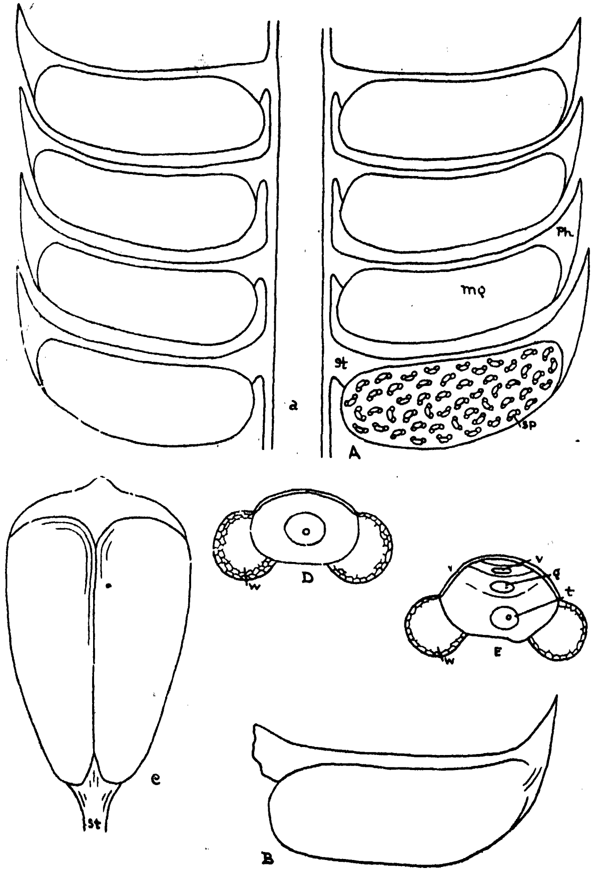
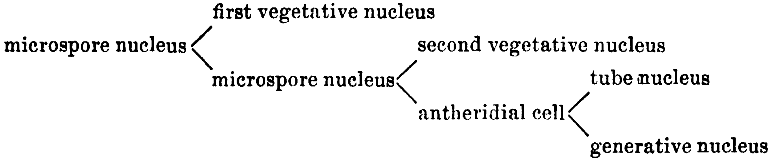


Fig. 209.—Pine. Details of a staminate cone. *A*, Portion of a microsporangiate strobilus (×10); *B* and *C*, two views of a microsporophyll (×12); *D* and *E*, two stages in the development of the microspore (pollen). *a*, axis; *st*, stalk; *Ph*, microsporophyll; *mg*, microsporangium; *sp*, microspore; *w*, wing; *v*, vegetative nucleus; *g*, generative nucleus; *t*, tube nucleus. (Drawn by Esther Ritter.)

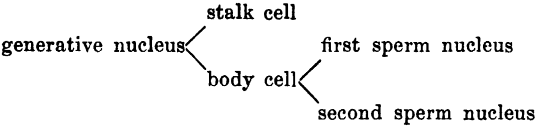
Development and Germination of the Microspore.—The microsporophyll has a stalk and an expanded scale. On the under side of the scale, and close to the side of the stalk, the microsporangia (pollen sacs) are attached. Microspores (pollen grains) are formed in tetrads by the usual two maturation divisions, each microspore having the haploid number of chromosomes.

Germination of the microspore begins before the pollen is shed, and by successive stages a gametophyte of six cells is finally formed. The completion of the process is delayed, however, until the pollen grain has been transferred to the ovule, when the last two divisions occur. The divisions occur as follows:

In the microsporangium



In the tissue of the nucellus



The six cells of the male gametophyte are as follows:

Two vegetative cells which disintegrate
Tube cell
Stalk cell
Two sperm cells (pollen tubes)

All these cells have the haploid number of chromosomes and the tissue is called the endosperm. Only one of the sperm nuclei functions as a sperm cell.

Development and Germination of the Macrospore.—The macrosporophyll consists of a short stalk, a scale, and a bract. The macrosporangia are two oval swellings near the base of the scale on the upper side. The tissues of the ovule are continuous with those of the scale except at the base where the micropyles open.

The tissue of the macrosporangium is the nucellus, and it is surrounded by a single integument which later forms the seed coat.

Early in the spring of the first year the single macrospore mother cell undergoes reduction, and four macrospores are formed in a linear series. Of these only the one farthest from the micropyle functions as an egg, the other three disintegrating.

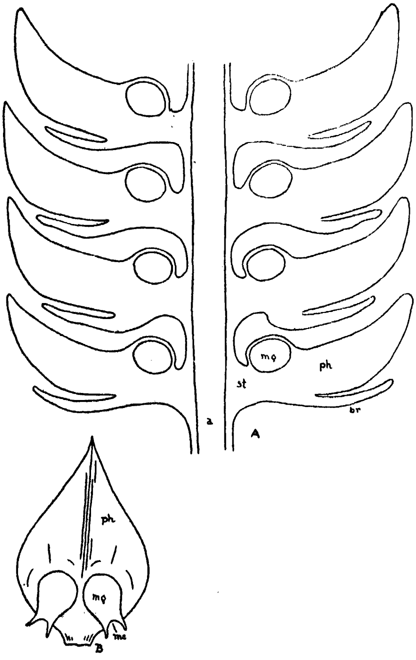


Fig. 210.—Pine. Details of a carpellate cone in the spring of the first year. *A*, Portion of the macrosporangiate strobilus (×5). *B*, A macrosporophyll (×6). *a*, axis; *st*, stalk; *br*, bract; *ph*, macrosporophyll; *mg*, macrosporangium (ovule); *mc*, micropyle. (Drawn by Esther Ritter.)

After pollination has occurred, the macrosporophylls close in and are sealed with a sticky substance. During the year which follows the gametophyte tissue is formed by free nuclear division in the macrospore. Cell walls later form around the nuclei and a solid mass of endosperm tissue is formed. This tissue is the female gametophyte.

In the late spring of the second year a few archegonia develop. These differ from the archegonia of the pteridophytes, and no tissue projects above the nucellus. No neck canal cells are formed, but the archegonium contains a large cavity in which one egg cell and one ventral canal cell are formed. A double row of neck cells fill in the opening of the archegonium, four cells to a row. All except the egg cell disintegrate before the time of fertilization.

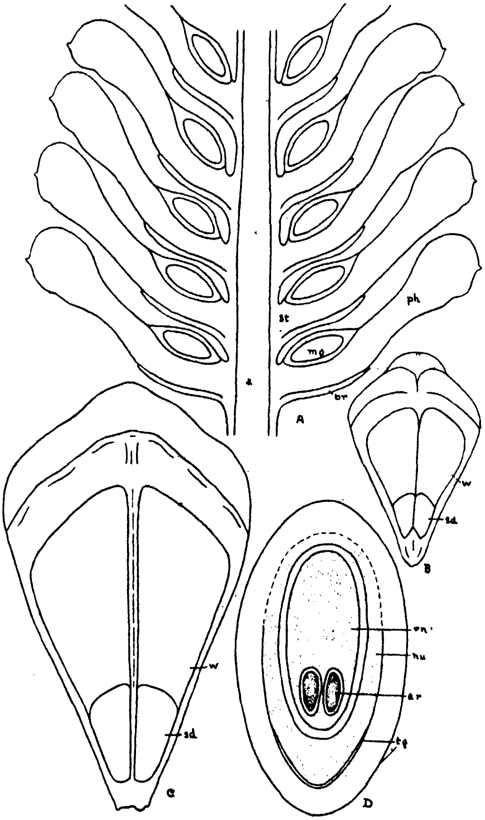


Fig. 211.—Pine. Details from carpellate cones of the second year. *A*, Portion of the macrosporangiate strobilus, early spring of second year (×4); *B*, a macrosporophyll from *A* (×3¼); *C*, a macrosporophyll from a cone of the late spring, second year, with mature seeds (×3¼); *D*, section of an ovule from *C*. *a*, axis; *st*, stalk; *br*, bract; *ph*, macrosporophyll; *mg*, macrosporangium; *w*, wing; *sd*, seed; *en*, endosperm; (female gametophyte) *nu*, nucellus; *tg*, integument; *ar*, archegonium. (Drawn by Esther Ritter.)

Fertilization and Development of the Embryo.—When the pollen tube, after a long delayed growth, finally reaches the tissue of the nucellus, the egg is mature, and the two nuclei

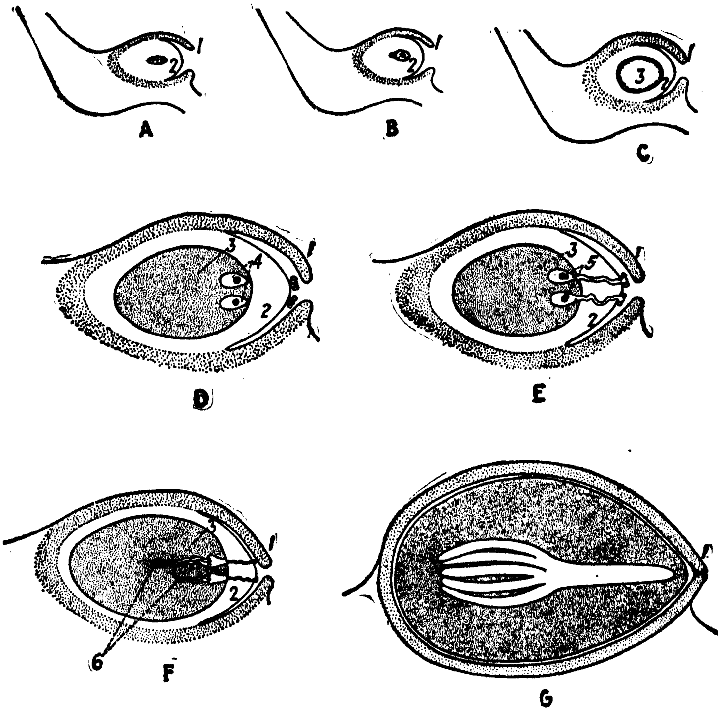


Fig. 212.—Development of the female gametophyte and seed in the pine. Longitudinal sections through the base of the cone scale. *A*, Young ovule containing a row of four macrospores; *B*, enlarged macrospore after abortion of the other three; *C*, young gametophyte (embryo sac), resulting from the germination of the macrospore. A layer of free nuclei surround a vacuole. *D*, Mature female gametophyte. Pollen grains have entered the micropyle. *E*, Fertilization. Union of female and male nuclei after growth of pollen tubes through the nucellus. *F*, Two embryos; *G*, the mature seed. *1*, Integument (becomes seed coat in *G*); *2*, nucellus; *3*, embryo sac containing endosperm; *4*, archegonia; *5*, egg nucleus; *6*, young embryos. (Reprinted by permission from Sinnott: Botany, Principles and Problems. Published by the McGraw-Hill Book Co.)

unite to form the zygote which marks the beginning of a new sporophyte generation. Development proceeds without further delay.

Free nuclear divisions occur in the zygote by which four nuclei are formed. These migrate to the base of the zygote and divide a third time, after which cell walls cut in. The eight cells are then in two tiers of four cells each, the cells of the upper tier being only partially cut off from the cytoplasm. The eight cells divide again to form sixteen cells in four tiers. These constitute the *proembryo.*

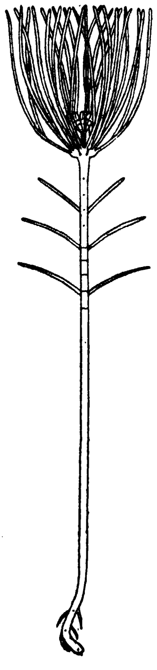


Fig. 213.—Young seedling of a white pine, showing many cotyledons. (Drawn by Esther Ritter.)

The four cells in the tier next above the apical tier then elongate greatly to form the suspensor cells. By their growth they push the apical cells deeper into the endosperm tissue. The eight upper cells remain in the egg and absorb food for the developing embryos.

As each of the four apical cells forms an embryo, and as there are often several archegonia formed, it follows that many proembryos are developing in a single ovule. Eventually one suppresses all the others, however, so that there is but one embryo in the mature seed.

The successful embryo develops a *radicle* (root), a *hypocotyl* (stem), a *plumule* (leaf), and three or more *cotyledons*.

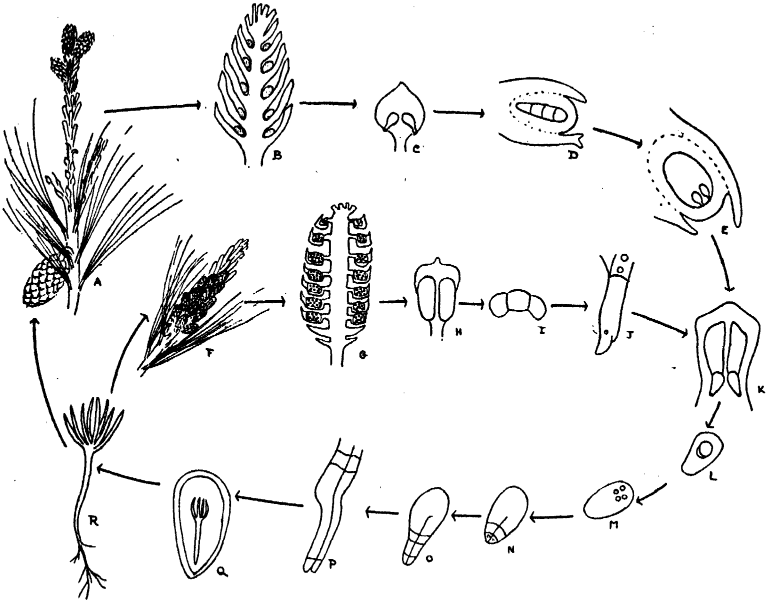


Fig. 214.—Diagrams to show the life cycle of the pine. *A*, Sporophyte branch bearing carpellate cones. *B*, A macrosporangiate strobilus; *C*, a macrosporophyll, showing macrosporangia; *D*, macrospores formed by the spore mother cell; *E*, archegonia in endosperm tissue just prior to fertilization; *F*, sporophyte branch bearing staminate cones; *G*, a microsporangiate strobilus; *H*, a microsporophyll; *I*, a microspore; *J*, microspore at the end of one year and just prior to fertilization; *K*. the macrosporophyll at the end of one year; fertilization takes place by the growth of the pollen tube through the micropyle in *K* to reach the nucellus; *L*, ovule during fusion of nuclei; *M*, free nuclear division; *N*, *O*, and *P*, growth of the proembryo; *Q*, seed containing embryo with numerous cotyledons; *R*, germination of seed to form sporophyte.

FLOWER-BEARING TYPE

Angiosperms

In replacing the strobilus by the flower, the angiosperms have completed the reduction of gametophyte tissue to a parasitic state. The strobilus lends itself easily to wind pollination, but the flower is peculiarly adapted to insect pollination. Therefore, there has developed in the angiosperms a wide variety in flower shapes, in bright colors and attractive scents from the volatile oils, all of which aid in accomplishing this end.

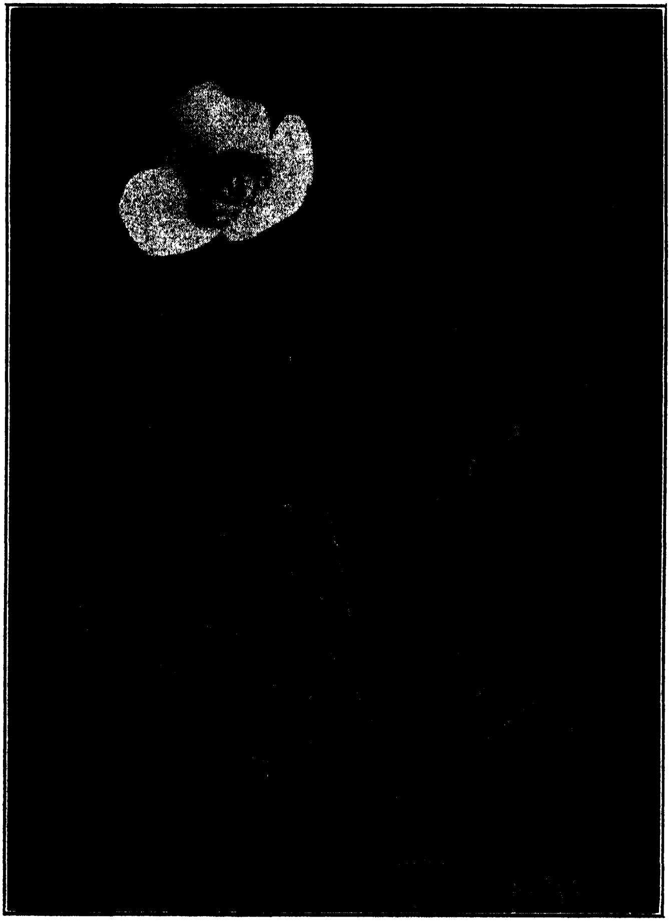


Fig. 215.—Mariposa lily, *Calochortus gunnisonii* of Colorado, showing the three-parted flower of the monocotyledon. (Courtesy of the American Museum of Natural History.)

Two large groups are distinguished: the dicotyledons and the monocotyledons. Although somewhat simpler in structure, the monocotyledons are believed to be derived from the dicotyledons. The life cycles are strikingly similar in the two groups, but they differ in four outstanding structural characters.

DICOTYLEDONS	MONOCOTYLEDONS
Flower parts in fours or fives or multiples of fours or fives	Flower parts in threes or multiples of three
Veins of the leaf netted	Veins of the leaf parallel
Vascular bundles in a ring	Vascular bundles scattered
Two seed leaves	One seed leaf

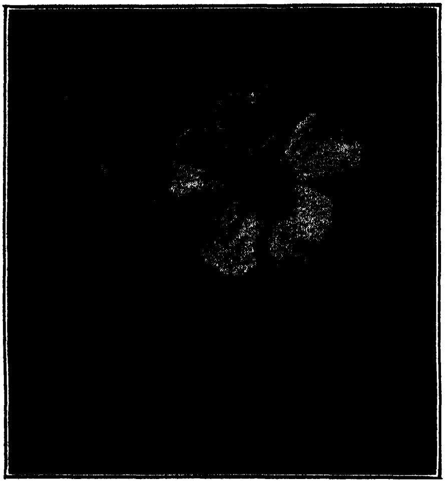


Fig. 216.—*Rosa virginiana,* the pasture rose, showing the five-parted flower of the dicotyledon. (Photograph by Clyde Fisher. Courtesy of the American Mesum of Natural History.)

Adaptations in Angiosperms

The angiosperms cover a wider range than any other group of plants, and adaptations to every type of environment have been developed. Plants which live in normal environments are called *mesophytes,* those adapted to life in the water are *hydrophytes,* and those adapted to desert life are *xerophytes.* In becoming adapted to these many environments, every organ of the plant has been subject to variations and to such an extent that each organ has, in some cases, taken on the function of every other organ. Thus both stems and leaves may act as absorbing organs, normally a function of roots; stems and roots may take on food manufacture, the chief function of leaves; leaves and roots may lend support to the plant and store food and water, the main function of stems; while roots, stems, and leaves may all lead to vegetative reproduction, thus multiplying the plants, which is the sole function of the seed.

In general, plants adapted to an intermediate environment with summer and winter seasons and neither excessively wet or dry soil have the most normal functions. Xerophytes will use stems for photosynthesis and leaves for water storage.

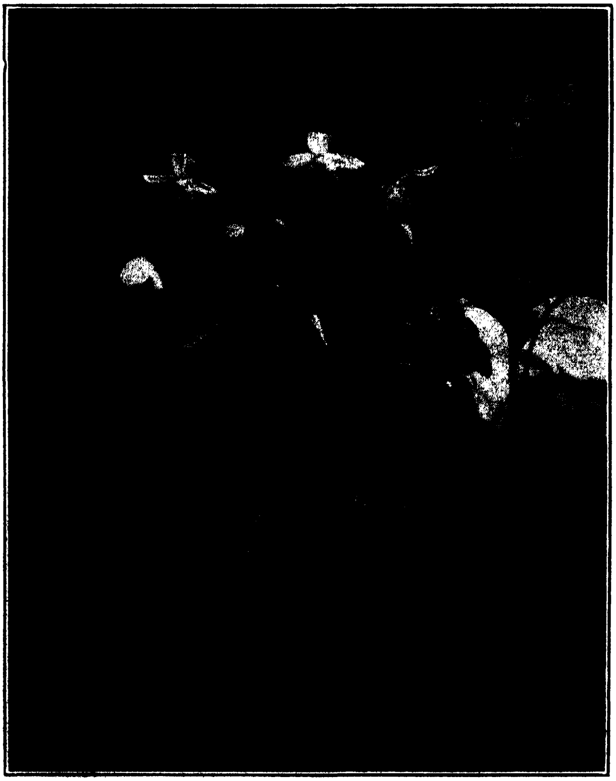


Fig. 217.—The showy lady's slipper, *Cypripedium reginae*. A monocotyledon of the orchid family, showing parallel venation of the leaves. (Courtesy of the American Museum of Natural History.)

Such leaves are heavily cutinized to prevent loss of water. Plants in very moist environments may use roots for photosynthesis and stems or leaves for absorption. There is no cutin on stems and leaves under water, and aerial organs of hydro-

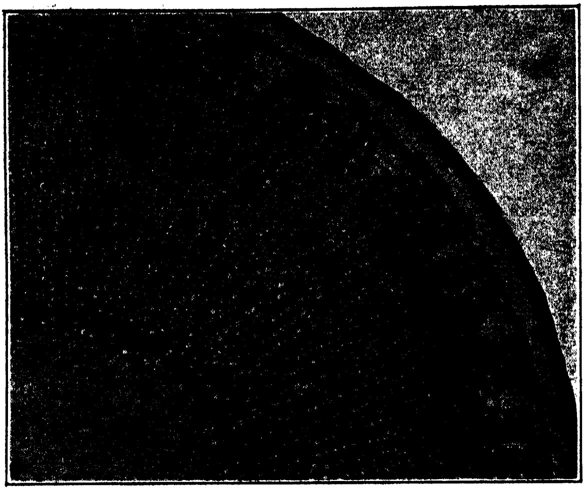


Fig. 218.—Dicotyledon, sector of the stem of the basswood, Tilia, showing arrangement of bundles in a dicotyledon.

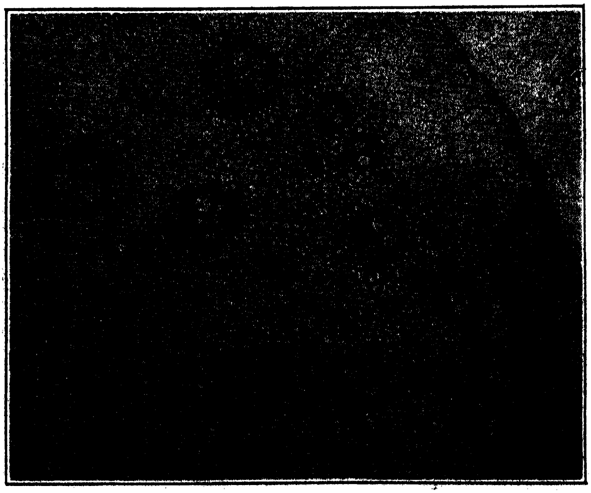


Fig. 219.—Monocotyledon, sector of the corn stem, showing arrangement of bundles in a monocotyledon.

Fig. 220.—Mesophytic vegetation with small pool in right foreground. Yellow birch tree (*Betula lutea*) with adventitious buds in center. Pennsylvania State Forest at Mount Alto. (Photograph by David Kribs.)

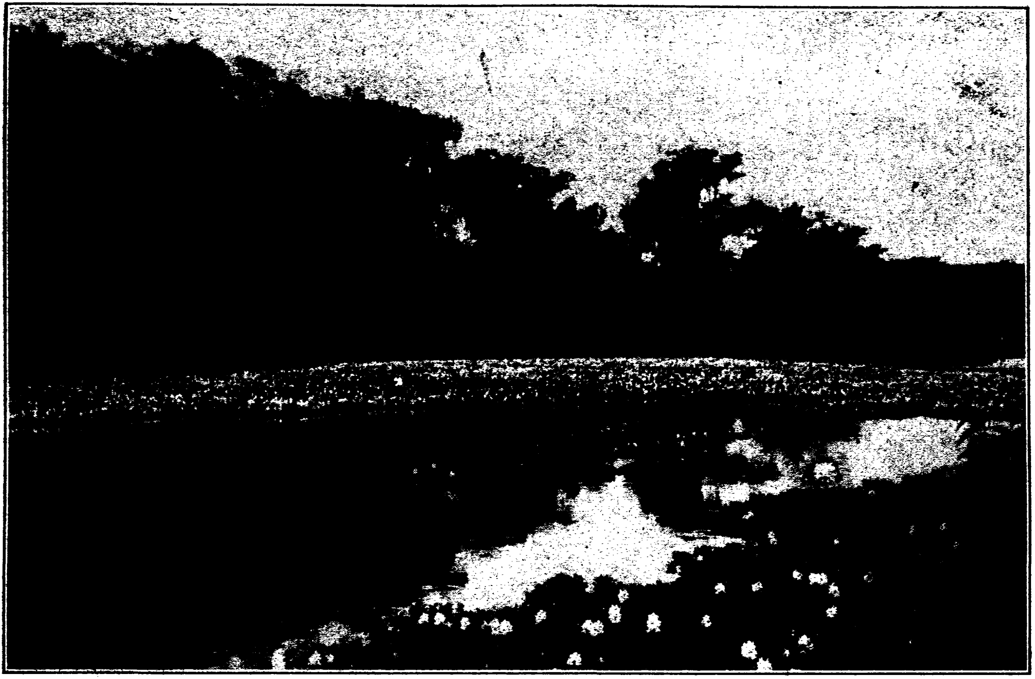


Fig. 221.—Hydrophytic vegetation. Eastern shore of Lake Okeechobee, Florida: Water hyacinth (*Eichhornia crassipes*) forms floating vegetation in foreground. Graded bog vegetation forms the strata of the shore. Grasses, sedges, and low trees grade into the bald cypress swamp (*Taxodium distichum*) on the hammock in the rear. Epiphytic Spanish moss (*Dendropogon usneoides*) hangs from the cypress trees. (Photograph by John K. Small.)

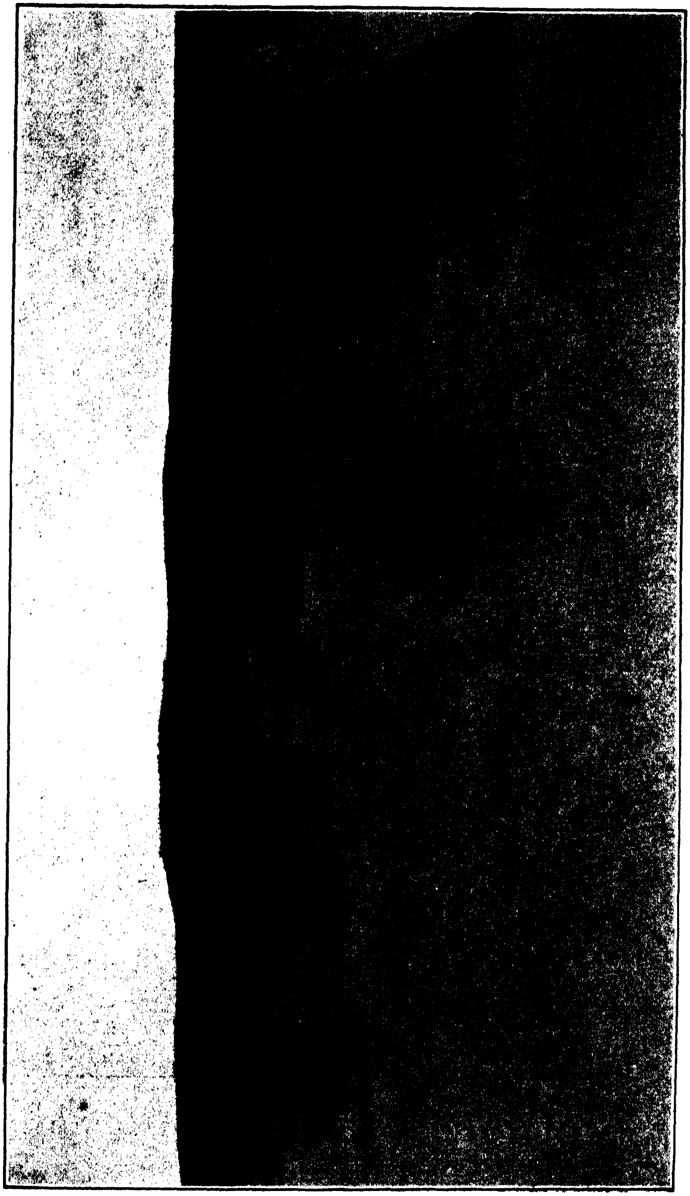


Fig. 222.—Xerophytic vegetation. Desert in Texas. (Photograph by John K. Small.)

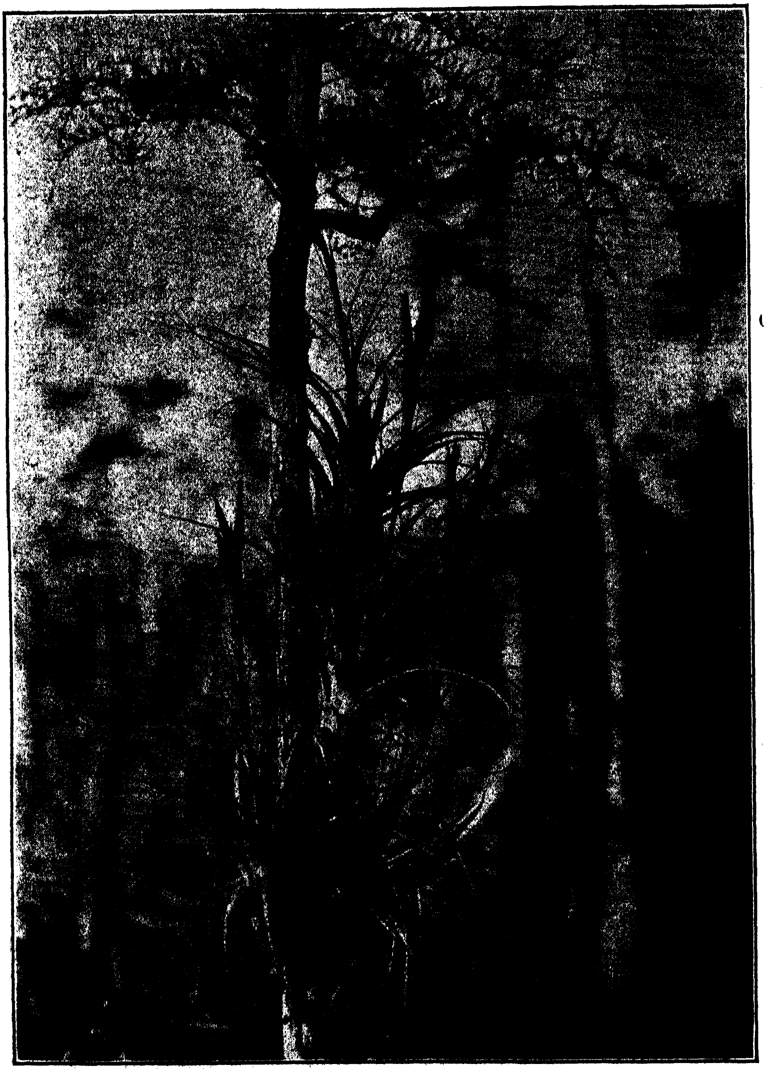


Fig. 223.—Epiphytic wild pine *(Tillandsia polystachya)* growing on the trunk of a pond cypress *(Taxodium ascendens)*. From cypress swamp near the Everglades, Florida. (Photograph by John K. Small.)

phytes are very thinly cutinized. A few common examples of such specializations will serve to illustrate the great versatility of the group.

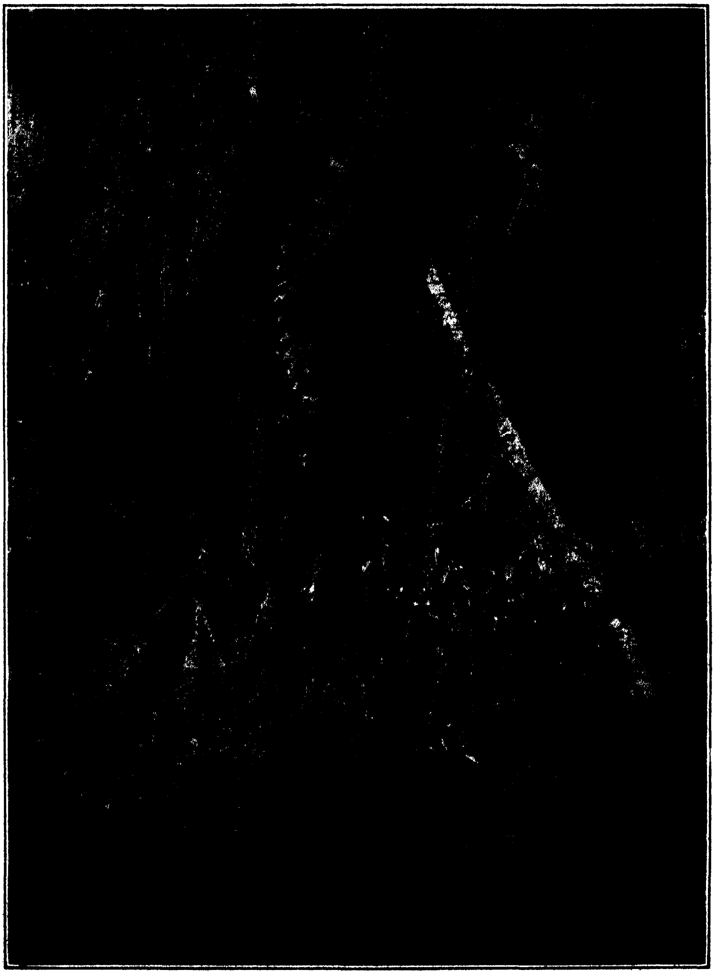


Fig. 224.—Epiphytic Spanish moss *(Dendropogon usneoides)*. Detail to show finely divided leaves of the epiphyte used for absorption. (Photograph by John K. Small.)

Absorption.—*Stems.*—Absorption is primarily the function of root hairs, but submerged hydrophytes, having no cutin on the stems, absorb water and salts easily. Parasitic plants often send out branches from the stem called *haustoria,* which penetrate the tissues of the host and absorb nourishment. Example —Cuscuta, a parasitic vine.

Leaves.—Many tropical plants are epiphytes—that is, they depend on other plants for support, but not for water and food. Such plants in very damp regions absorb almost entirely through aerial leaves. These are finely divided and covered completely with absorptive hairs. They hang down from the supporting plant in long feathery strands. Example —Spanish moss *(Dendropogon usneoides).*

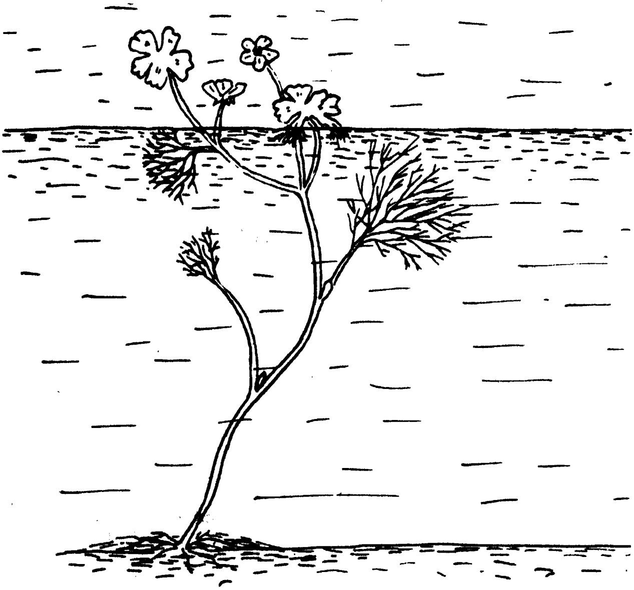


Fig. 225.—Water crowfoot *(Ranunculus aquatilis).* Submerged leaves dissected and used for absorption.

In water plants the leaves beneath the surface of the water become finely dissected and are not cutinized, while those above the surface are entire. In not all such cases are the leaves beneath the surface absorptive, but in the bladderwort (Ceratophyllum), and in the water crowfoot *(Ranunculus aquatilis)* the leaves above the surface of the water are entire and function by photosynthesis and transpiration, while the dissected leaves beneath the surface are absorptive.

In the floating duckweed, the leaf is flattened into a thallus-like structure. A few water roots extend into the water, but absorption occurs mainly on the under surface of the floating leaf. The upper surface performs photosynthesis.

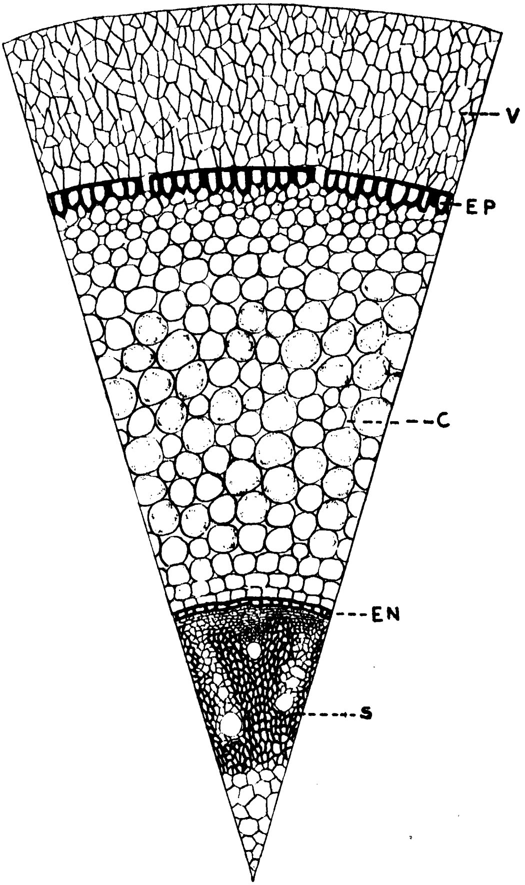


Fig. 226.—Aerial root of Orchis sp. showing velamen. The loose cells hold water for long periods allowing gradual absorption. *V*, Velamen; *EP*, epidermis; *C*, cortex; *EN*, endodermis; *S*, stele. (Drawn by Frances Fiske.)

Digestion and absorption are functions of the leaf in insectivorous plants. Pitcher plants have their leaves modified to form pitchers which catch and hold water in which insects are drowned. In the genus *Sarracenia,* the insects are decomposed by bacterial action before absorption, while in *Nepenthe* digestive juices are secreted by the leaf. The sundews *(Drosera)* have leaves which are covered with glandular stalks which bend toward any insect caught on the sticky secretions and so engulf them with digestive juices. The Venus's fly-trap *(Dionaea muscipula)* has the petiole of the leaf expanded into a blade-like structure of two halves. Bristles on the edges of the blades are stimulated when insects brush against them, and the two halves of the blade snap together thus closing the trap. Digestive juices are then secreted into the closed chamber.

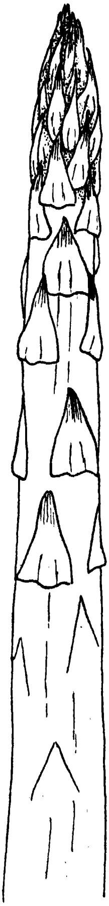


Fig. 227.—*Asparagus officinalis.* Stem used for photosynthesis and storage. Leaves reduced to bracts.

Roots.—Absorption is normally the function of underground roots with root hairs. Roots which develop under water are devoid of root hairs, and the absorption has to be performed by leaves or stems. Aerial roots, however, are often absorptive. The epiphytic orchid, *Epidendrum ramosum,* has aerial absorptive roots which arise from the nodes of the stem. The tip of the aerial root is covered by a *velamen* which fits over the tip like a glove finger. It is several layers of cells thick and absorbs water like blotting paper, the cells of the velamen retaining the water for hours. This makes it possible to accumulate water from raindrops and dew, and surround the root cells with a condition similar to that in the soil. Example—Wild fig *(Ficus brevifolia).*

Photosynthesis and Aeration.—The greater part of the food manufacture with the accompanying functions of aeration and transpiration are performed by the foliage leaves of the seed plants, yet, in many cases, other organs take on the function also.

Roots.—There is an orchid, *Taenophyllum,* with a very short stem and no leaves in which photosynthesis is performed entirely by aerial roots.

Aeration is a function of roots in plants with submerged roots. The large roots run horizontally beneath the surface, and send small roots vertically up to extend beyond the surface. These exposed tips have very large air passages and absorbed air is diffused rapidly to the submerged roots below.

Stems.—The stems of herbs are green throughout the life of the plant and always aid in food manufacture, and the young stems of woody plants function in a similar way temporarily.

There are also stems specialized for photosynthesis. The upright stem of the asparagus is the only photosynthetic organ for the plant, since the leaves are reduced to mere bracts, and in the cactus plants, the stems are thickened and succulent for water storage, but have chloroplasts for photosynthesis also. The almost erect position of the leaves aids in avoiding the direct rays of the too intense sunlight.

Support.—Support is primarily the function of the stem, but many stems are not strong enough to support the plant and must be assisted by other organs.

Roots.—In corn adventitious roots grow out in whorls from the lower nodes and give additional support to a weak stem. These are called *brace* roots.

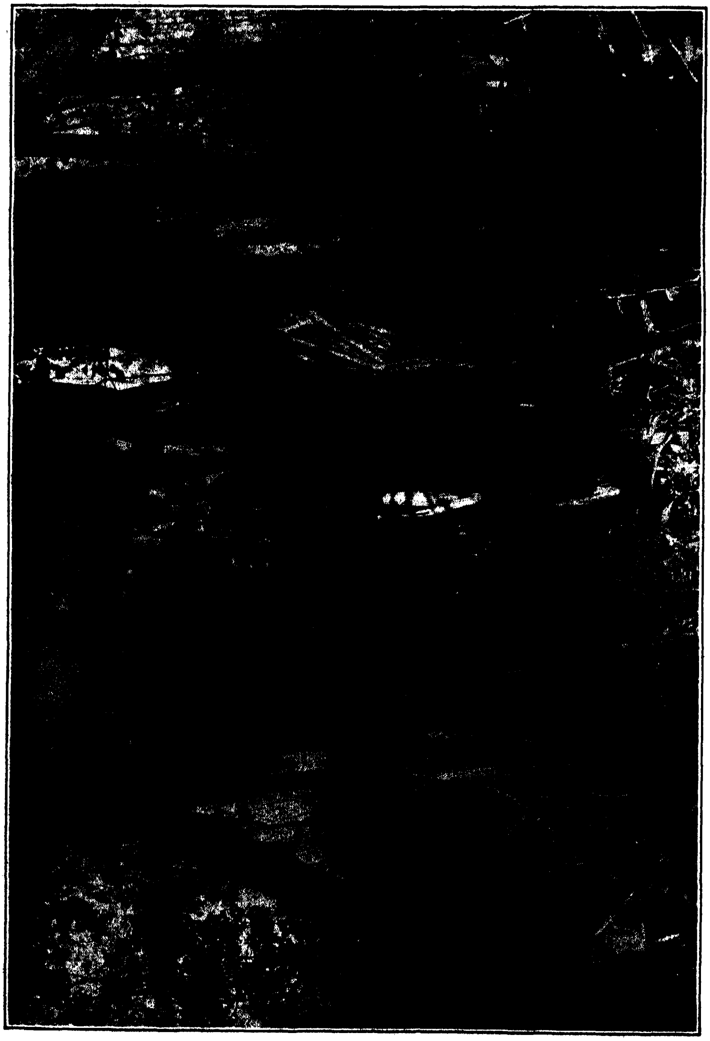


Fig. 228.—Prop roots of the native banyan, or wild fig (*Ficus brevifolia*) from vicinity of Cutler, Florida. (Photograph by John K. Small.)

The banyan tree sends down long roots from the horizontal branches which serve as secondary branches, and allow the tree to spread over a wide area. These are *prop* roots.

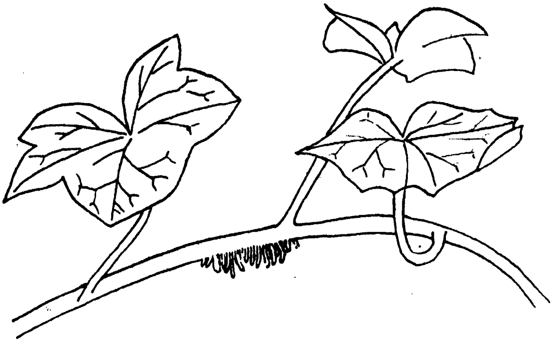


Fig. 229.—Boston ivy *(Parthenocissus tricuspidata).* Adventitious aerial roots used for support.

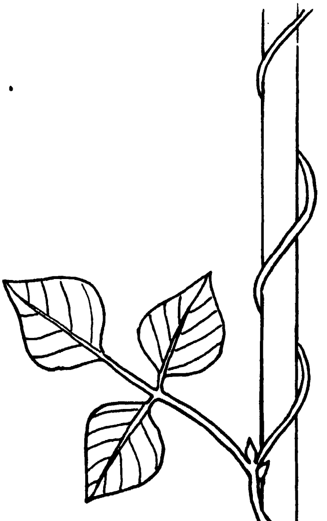


Fig. 230.—Bean *(Phaseolus diversifolium).* Twining stem for support.

Some climbing plants have adventitious aerial roots which are used for support. Example—Boston ivy *(Parthenocissus tricuspidata)*.

Stems.—Some plants have especially modified stems for the support of otherwise weak stalks. The bean *(Phaseolus)* and the morning glory *(Ipomoea)* have stems which twine about a support and maintain an upright position by leaning. Other stems and branches have been modified into tendrils which cling to supports as in the heartpea *(Cardiospermum)*. In the barberry the branches have been modified into spines.

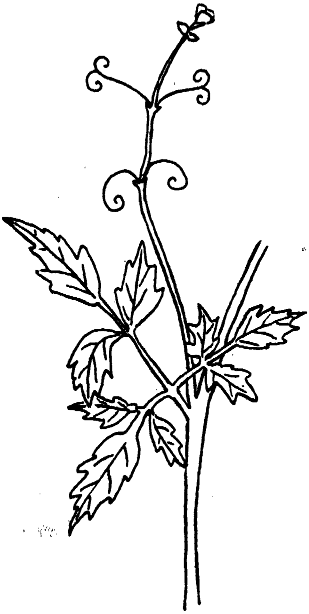


Fig. 231.—Heartpea *(Cardiospermum halicacabum)*. Stem modified to form tendrils. Terminal bud forming flower.

Leaves.—Leaves also aid in the support of the climbing plants by forming ***tendrils, spines,*** and ***hooks.*** In the nasturtium the petiole becomes a tendril, the tips of the compound leaf in the sweet pea are tendrils, and in clematis the stalk of the leaf is the part modified.

The climbing palms, or rattans, have hooks which are modified leaves, and the spines on the cacti are modified leaves. These, as in the spiny tip on the leaf of the century plant, are probably more protective than supporting, since desert plants are open to the depredations of browsing animals.

Storage.—Normally plants store excess food in the pith and parenchyma cells of the stem, but many special storage organs are formed for protection over long periods of inactivity. Special organs for water storage in desert plants and for air storage in water plants are also formed.

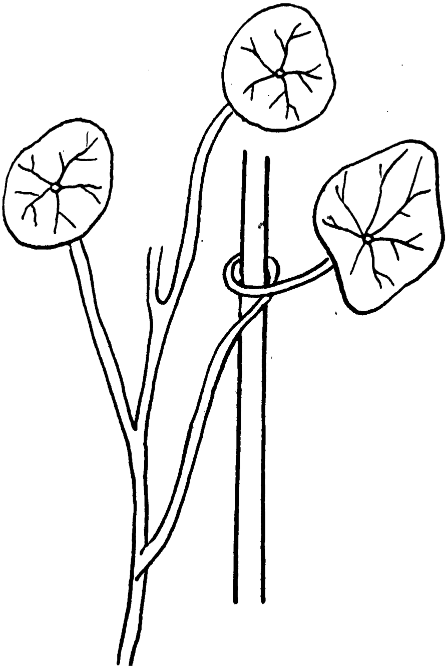


Fig. 232.—Nasturtium *(Tropaeolum majus)*. Petiole functioning as a tendril for support.

Food Storage.—*Roots.*—Many of the common vegetables are root storage organs. Generally they are enlargements of the primary root, and both the xylem and phloëm cells are modified, as in the radish and sweet potato. Turnips, however, store food in the xylem only, while the carrot and the parsnip use the bark in addition. In beets the food is laid down in alternate rows of xylem and phloëm.

Stems.—Special organs for food storage are formed in some underground stems. Rhizomes which are horizontal underground stems develop *tubers* for food storage. Sometimes these develop at the end of the rhizome, as in the white potato.

Upright underground stems sometimes accumulate food, as in the *corm* of the crocus, and special thickening of the trunk above ground accommodates large amounts of starch in the sago palm, which provides the starch used in tapioca.

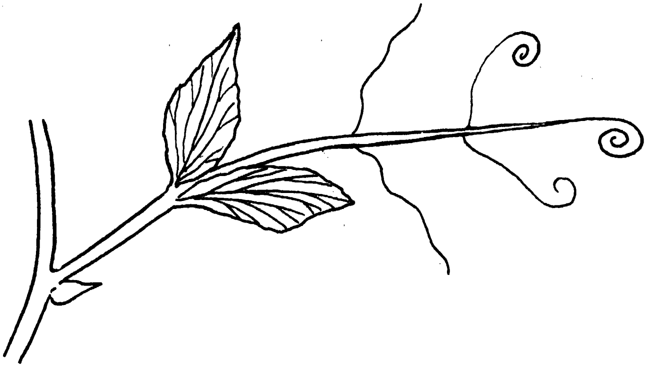


Fig. 233.—Sweet pea *(Lathyrus odoratus)*. Compoundly pinnate leaf with two pairs of pinnae and the tip of the leaf modified into tendrils.

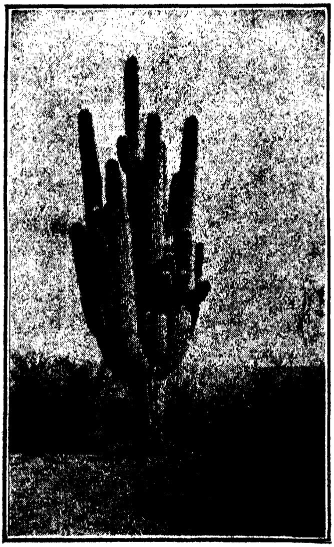


Fig. 234.—A giant cactus *(Carnegia gigantea)*, growing in the desert region of southwestern United States. (Reprinted by permission from Textbook of General Botany, by Holman and Robbins. Published by John Wiley & Sons, Inc.)

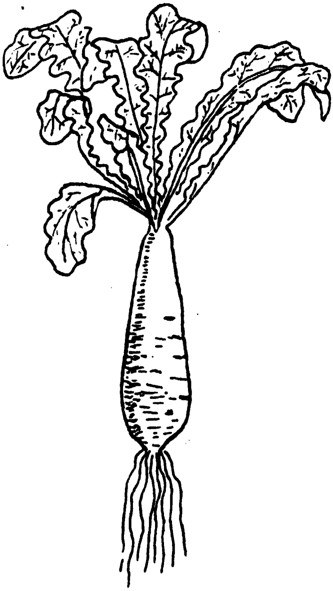


Fig. 235.—Radish *(Raphanus sativus)*. Tap root used for food storage.

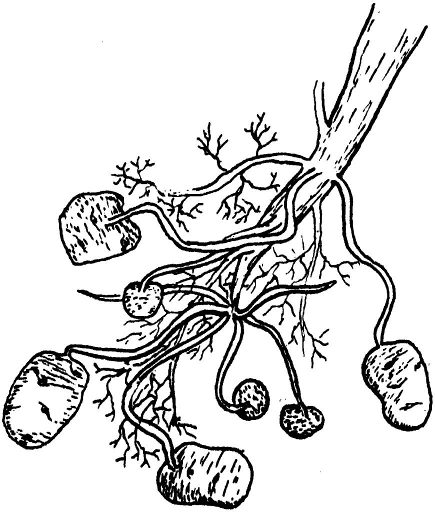


Fig. 236.—Potato *(Solanum tuberosum)*. Underground stem with food storage in tubers at the ends of the branches.

Leaves.—Some short vertical underground stems are enclosed by large fleshy scale leaves which store food, as in the bulb of the onion and lily. The heading of lettuce or cabbage is a similar formation above ground.

In the artichoke, the flower bud is enclosed in overlapping scale leaves, with cells for food storage.

AIR STORAGE.—Air storage is a specialization for floating. The floating organs are chiefly leaf blades or petioles. The tissue is loose and has large air spaces, and often the organ becomes bulbous, as in the petiole of the water hyacinth.

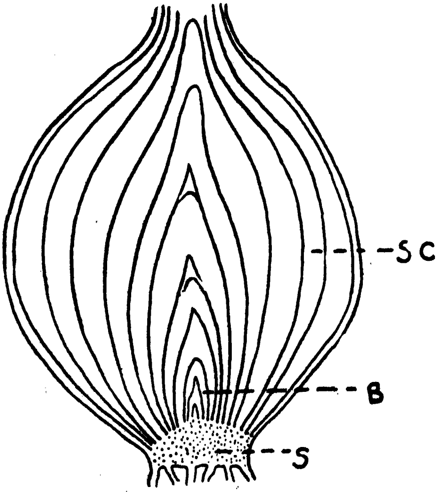


FIG. 237.—Onion bulb (*Allium* sp.). Food storage in leaves. *S*, Stem; *B*, bud; *SC*, scale leaves.

WATER STORAGE.—Water storage tissue is typical of desert plants. It is found in the stems of the cacti and the leaves of the century and rubber plants.

Vegetative Reproduction.—The propagation of the species is primarily the function of the seed and involves the union of micro- and macrogametes. Many seed plants have a much swifter method of multiplying and spreading the sporophyte plants by vegetative propagation. Some plants do this naturally, but many more can be induced to do so by cuttings. In some plants this power is possessed by the roots, in others by stems, and in still others by leaves. Often more than one organ in the same plant may be induced to propagate vegetatively, but when the method is natural, it is more often confined to a single organ.

Roots.—The silver poplar spreads a ring of young trees around the parent tree by sending stems up from the underground roots. Poplars and willows will do the same if the roots are exposed to the air, but not otherwise. The cottonwood and dandelion can be induced to develop stems from the roots if the entire root system is removed and exposed to air.

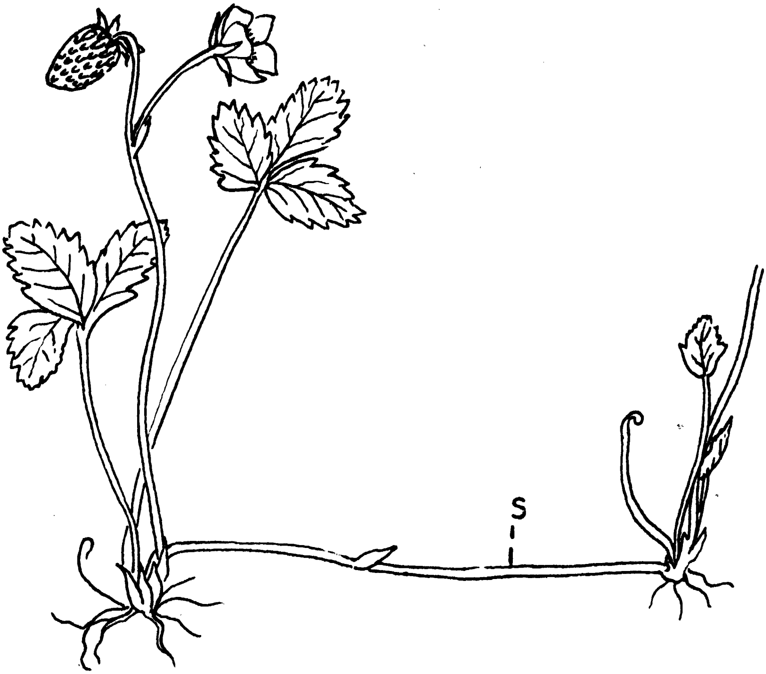


Fig. 238.—Strawberry *(Fragaria americana)*. Vegetative reproduction by stems. Note leaf at node of stolon. A new plant grows from each alternate node. *S*, Stolon.

Stems.—The natural methods of vegetative propagation by stems are the swiftest methods known.

Underground *rhizomes* running horizontally produce tubers which, in turn, produce buds to start new plants. The tubers are enlargements for food storage. They may occur at the end of the rhizome, as in potatoes. Water plants with rhizomes spread rapidly as bulrushes, flags, and water lilies.

Runners grow over the surface of the ground sending down roots at the nodes. The strawberry spreads in this manner. The rapid spread of many water plants is due to fragmentation of stems. Aquatic stems are very readily detached, and the fragments may float some distance, thus carrying the species over new areas and rapidly covering a waterway. Water cress and the water hyacinth spread thus rapidly, the latter often filling streams so quickly as to impede navigation (see Fig. 221).

Begonia plants may be induced to produce roots from cut stems.

Leaf.—Bryophyllum has a notched leaf which can produce roots at all the notches. Begonias can be induced to propagate from leaf cuttings.

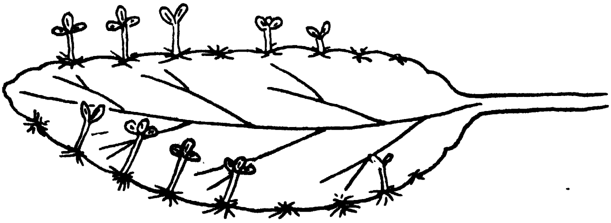


Fig. 239.—*Bryophyllum.* Vegetative reproduction at the notches of the leaf.

The Flower

The flower of the angiosperms is in reality a branched stem. The leaves borne on the stem are sporophylls which are specialized for the protection of the gametophyte. They have, therefore, lost all resemblance to the foliage leaves and are known as the floral leaves. These are the showy parts of the flower and are variously colored. Sometimes foliage leaves are also colored when they surround small and inconspicuous flowers. In the dogwood it is the *bracts* which are showy; in the poinsettia it is the entire *leaf blade*.

In the flower the sporophylls are in whorls about an axis instead of in spirals as in the cone. The spiral formation is retained, however, in the more primitive families. The microsporophylls are the *stamens,* and the macrosporophylls, the *carpels.* In some species these are on separate plants, but more often the microsporophylls are in whorls around the macrosporophylls. Cross-pollination is the rule in either case. The whorls of fertile sporophylls are surrounded by whorls of floral leaves that form the *perianth.* These are the *petals* and *sepals.* In some flowers both whorls are colored; in others, the sepals are green.

Male Organs.—Each stamen consists of a slender *filament* which is a petiole, and an *anther* which is a reduced leaf blade. In the anther are the *pollen sacs* which are microsporangia, and these form microspore mother cells, each of which by reduction forms four *pollen grains,* the microspores.

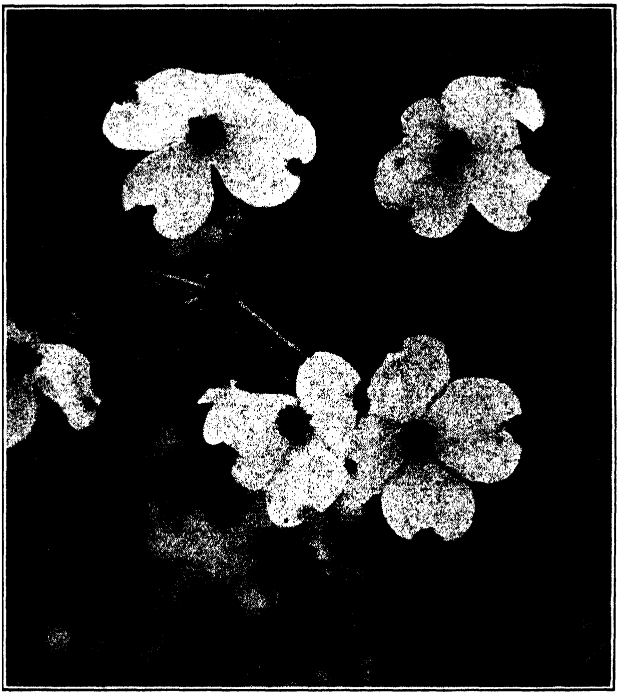


Fig. 240.—Dogwood *(Cornus florida).* Petal-like bracts surrounding small and inconspicuous flowers. (Photograph furnished by the Wild Flower Preservation Society, Washington, D. C.)

Within the pollen grain the protoplast forms two nuclei, the *tube nucleus* and a *generative nucleus.* These nuclei represent two cells of the developing gametophyte, but no cell wall forms between them. This is the condition in which the pollen grains are shed.

Female Organs.—The *pistil* is formed of separate *carpels.* This, being the central whorl, is attached to the main axis of the flower which is a stem and is called the *peduncle*. If more than one flower is attached to the stem, each separate stem is a *pedicel*. The apex of each peduncle or pedicel is flattened and broadened into a *receptacle*, and to this portion of the axis the pistil is attached. It will be simple or compound, according as it is composed of one or more carpels.

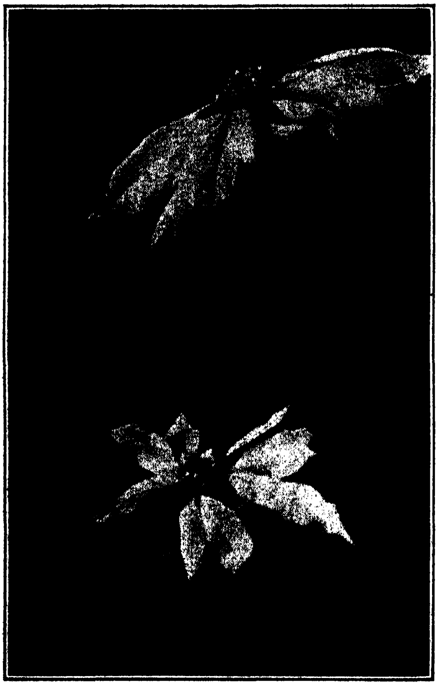


Fig. 241.—Poinsettia *(Euphorbia pulcherrima)*. Petal-like foliage leaves surrounding inconspicuous flowers. (Photograph furnished by the Wild Flower Preservation Society, Washington, D. C.)

The pistil has three regions: the swollen basal region, the *ovary;* a long column of tissue, the *style;* and an expanded upper end, the *stigma*. This frequently has a rough, sticky surface which serves to catch and hold the pollen grains.

In the ovary the macrosporangia are borne on the carpels. These are the *ovules*. Each ovule is attached to the carpel by a short stalk, the *funiculus*. The region of attachment is called the *placenta,* and sometimes marks the line of fusion between carpels.

Ovule.—The ovule develops as a protuberance of growing cells, the *nucellus.* From it develop two layers of protective tissue, the *integuments,* which grow about the nucellus so as to leave an opening, the *micropyle,* through which the pollen tube enters.

In the nucellus develops the *embryo sac* which is the macrospore. Within the embryo sac the female gametophyte develops by nuclear divisions in the protoplast. Cell walls are not usually formed. There are three divisions:

1. At the first nuclear division the nuclei separate, going to the poles of the embryo sac.
2. Each nucleus divides a second time forming two nuclei at each pole.

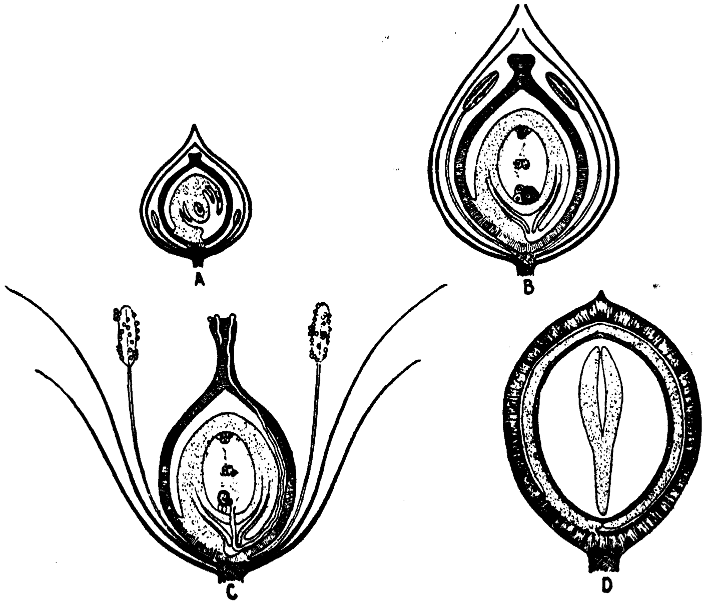


Fig. 242.—Longitudinal diagrams of flower and fruit. Calyx and corolla are solid black; the ovule, seed coats, and embryo are dotted, and the ovary wall, stigma, and style are lined. *A,* Young bud, the stamens and ovule beginning to develop. *B,* Bud ready to unfold. The embryo sac within the ovule is fully developed, and the nucleus (below), and double endosperm nucleus (in center) are ready for fertilization. *C,* Fully opened flower. The anthers have burst, and pollination has taken place. Pollen grains on stigma. Two germinating grains are shown, one of which has penetrated the ovule through the micropyle. Double fertilization is taking place, one male gamete uniting with the egg nucleus, the other with the endosperm nucleus. *D,* Ripe fruit. Sepals, petals, and stamens have dropped off. The ovary wall has hardened into the pericarp, and the micropyle has closed. The integuments have become the seed coats, and the ovule has developed into the seed. The embryo in the center of the seed has grown from the fertilized egg, and the endosperm surrounding it from the endosperm nucleus. (From Sinnott: Botany, Principles and Problems. Published by the McGraw-Hill Book Co.)

3. Each of the four nuclei divides forming eight nuclei, four at each pole.

A single nucleus from each group then migrates to the center of the embryo sac. These are then called the *polar nuclei.* The three nuclei remaining at the end, opposite the micropyle, are the *antipodals.* One of the nuclei at the end nearest the micropyle becomes the *egg nucleus,* the other two are called *synergids.*

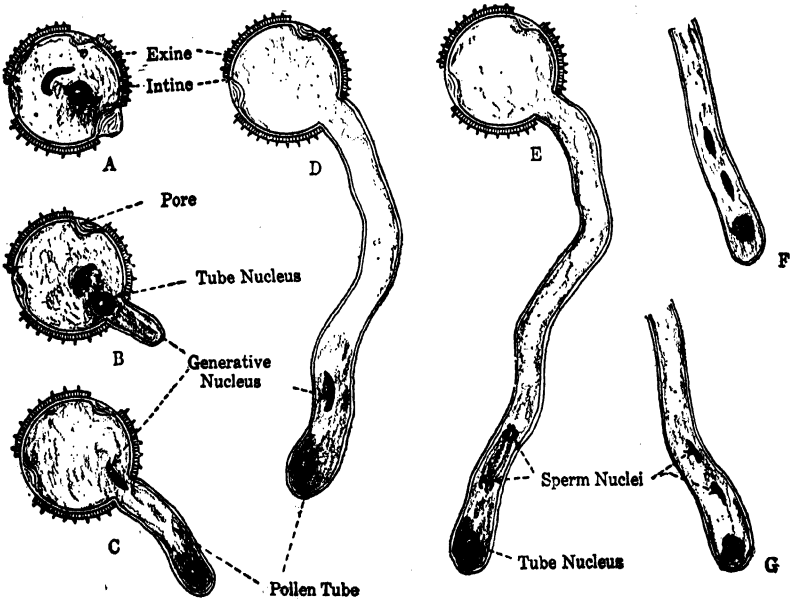


Fig. 243.—Stages in the germination of the pollen grain, and development of the pollen tube. (Reprinted by permission from Textbook of General Botany, by Holman and Robbins. Published by John Wiley & Sons, Inc.)

The female gametophyte before fertilization then contains the following eight nuclei of which the egg nucleus is the gamete:

One egg nucleus
Two polar nuclei
Two synergids
Three antipodals.

Fertilization.—When the pollen grains have become attached to the stigma of a pistil, they begin to germinate and a pollen tube grows out from each grain. In the tube the tube nucleus migrates to the tip, and the generative nucleus divides into two *sperm nuclei.* These are the gametes.

Although several pollen grains may germinate, only one tube may enter any one ovule. It grows through the tissue of the long style, the part behind the nuclei often drying up as the

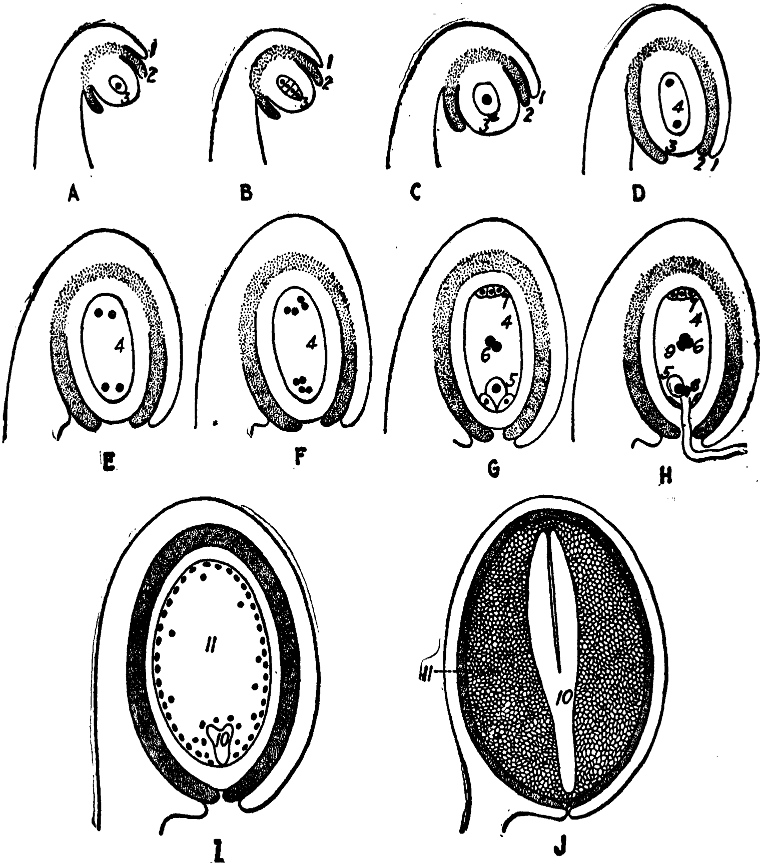


Fig. 244.—Development of the embryo sac and seed in a dicotyledonous seed plant. Longitudinal sections through the ovule and seed. *A*, Young ovule; *B*, four macrospores in a row; *C*, enlargement of one macrospore at the expense of the other three; *D*, division of macrospore nucleus; *E*, *F*, further divisions of nucleus; *G*, fusion of two polar nuclei to form fusion nucleus; *H*, entrance of two sperm nuclei; *I*, development of embryo and endosperm; *J*, mature seed. *1*, *2*, Integuments (seed coats in *J*); *3*, nucellus; *4*, embryo sac; *5*, egg nucleus and two synergids; *6*, fusion nucleus; *7*, antipodal nuclei; *8*, male nucleus which will unite with egg nucleus; *9*, male nucleus which units with fusion nucleus to form endosperm nucleus; *10*, embryo; *11*, endosperm. (Reprinted by permission from Sinnott: Botany, Principles and Problems. Published by the McGraw-Hill Book Co.)

progress goes on. On reaching the micropyle, the tube grows directly into the ovule and penetrates the embryo sac. The tip of the pollen tube then dissolves, discharging the two sperm nuclei and the tube nucleus into the embryo sac.

A double fertilization then takes place.

The egg nucleus fuses with one of the sperm nuclei to form the zygote which develops into the *embryo.*

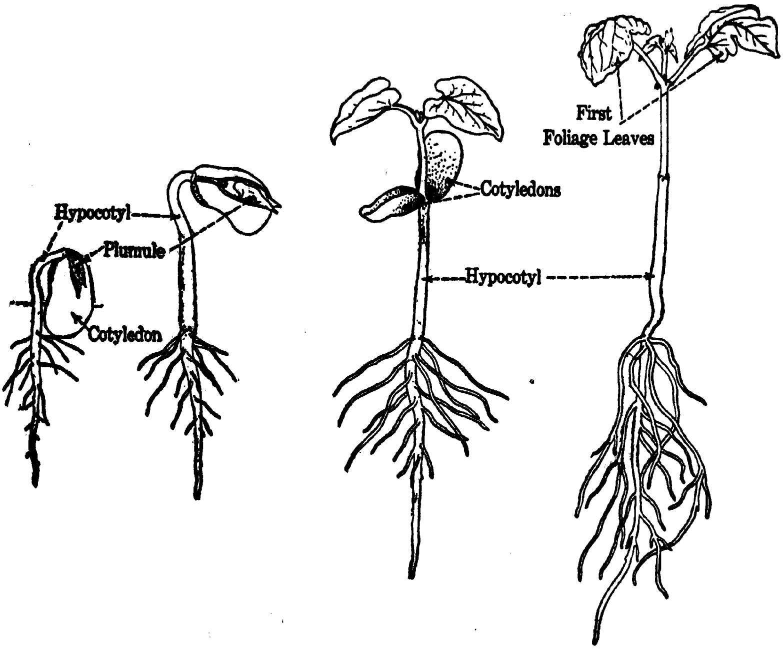


Fig. 245.—Stages in the germination of the common bean *(Phaseolus vulgaris).* (Reprinted by permission from Textbook of General Botany, by Holman and Robbins. Published by John Wiley & Sons, Inc.)

The two polar nuclei fuse to form a single fusion nucleus which unites with the other sperm nucleus to form the *endosperm nucleus* that develops into the *endosperm.*

The two synergids are usually destroyed as the pollen tube enters the embryo sac, but the antipodals persist for some time and may contribute to the nourishment of the endosperm or embryo. The tube nucleus eventually disappears.

The ovule then becomes the seed. The integuments form the seed coats. The developing embryo within the seed is the new sporophyte generation. It is nourished by the endosperm tissue.

Seed.—Many seeds are minute, but if the tissues outside the embryo sac increase in size after fertilization, it may become large. The outer integuments become the *testa* which may grow hard and woody and is very resistant to external conditions. The inner integument, the *tegmen,* is membranous. It does not always persist. Often the seed coats develop special structures, such as hairs and plumes, to aid in seed dispersal.

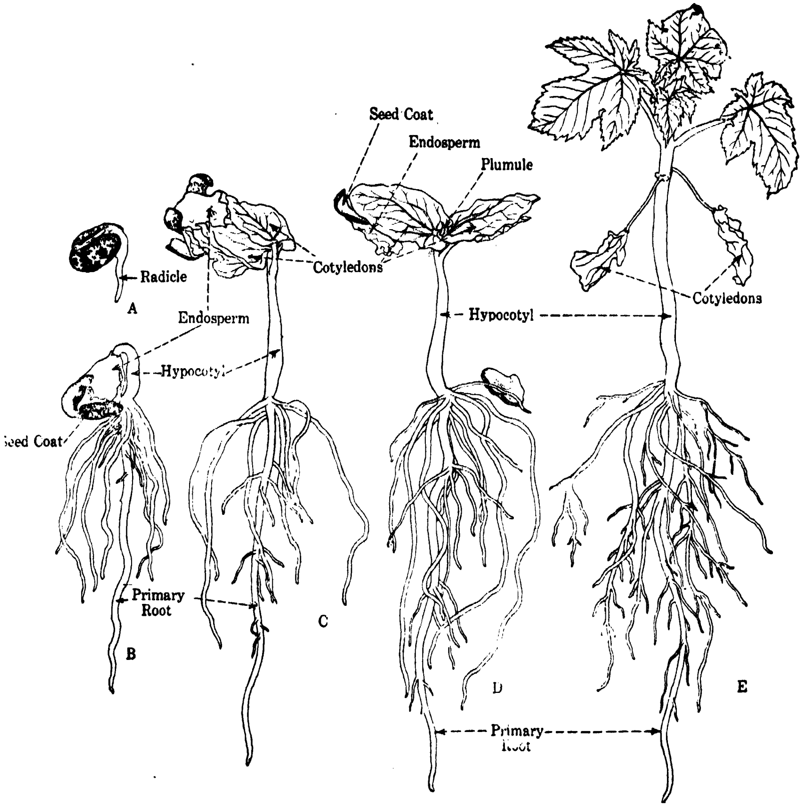


Fig. 246.—Stages in the germination of the castor oil seed *(Ricinus communis).* (Reprinted by permission from Textbook of General Botany, by Holman and Robbins. Published by John Wiley & Sons, Inc.)

When the seed is ripe, the endosperm has developed, by repeated divisions of the endosperm nucleus, into a mass of nutritive tissue, the cytoplasm of the cells having accumulated food during the process to provide for the future development of the embryo. In some plants, such as the common bean, the endosperm is absorbed into the cotyledons, and thus becomes a part of the embryo while still in the seed. In others, such as the castor oil bean, much of the endosperm remains in the ripe seed, and is not absorbed by the embryo until after germination.

The embryo has developed, meanwhile, into a rudimentary plant. It consists of a minute stem, the *hypocotyl,* a root, the *radicle,* a bud, the *plumule,* and seed leaves, the *cotyledons.*

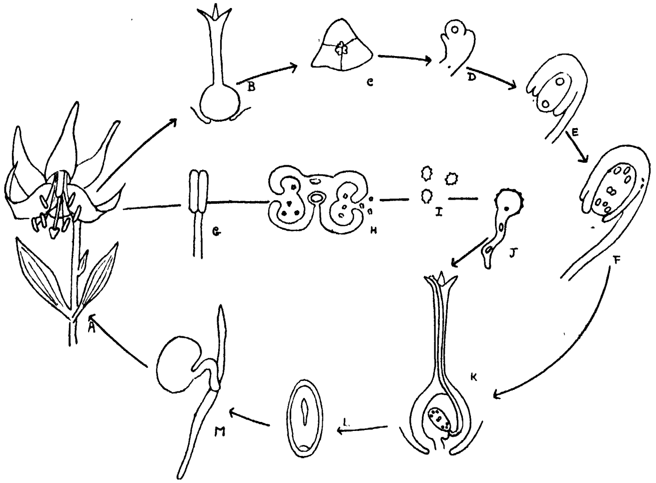


Fig. 247.—Diagram to show the life cycle of a lily. *A,* Mature sporophyte bearing flower; *B,* mature pistil; *C,* cross-section of ovary; *D, E,* and *F,* stages in the development of the macrospore; *G,* a stamen; *H,* cross-section of stamen showing pollen grains; *I,* pollen grains enlarged; *J,* a germinating pollen grain; *K,* the pollen grain has grown down the tube of the pistil and penetrated the micropyle; *L,* mature seed containing embryo; *M,* germinating seed which forms the sporophyte.

The seed remains in this condition until germination, which may be months or even years later. Only a minute amount of water is retained in the seed, and the outer coat is so resistant that this does not escape.

Germination.—The absorption of water and the application of heat are necessary to cause germination. This is usually accomplished by planting the seed. Until the water absorbed by the seed is used up, geotropic responses will control the direction of growth. Later the roots will respond to water, and curvatures may result. The seedling lives on the food in the endosperm until the plumule has developed young leaves which are capable of photosynthesis.

The Fruit

The fruit develops from the ovary. When ripe, the accessory organs, stigma, style, stamens, petals, etc., die and usually drop off. The sepals may also drop, but more often are left attached to the peduncle. The special function of the fruit is the dissemination of the seed, but because of the tendency to store food in ovary walls, the fruit is of especial interest to man as a food product. A few of the types are outlined below.

Simple fruits are those consisting of a single ovary.

Example—Bean and pea pod.

Aggregate fruits are those consisting of a number of ovaries belonging to a single flower and massed on the receptacle.

Examples—Strawberry (individual fruit, an akene).
Raspberry (individual fruit, a drupe).

Multiple fruits consist of ovaries of a number of flowers, more or less fused into a single mass.

Example—Pineapple.

False fruits are those in which the bases of the stamens, petals, sepals, and often the receptacles are united with the wall of the ovary. These may include fruits classed under any of the other headings.

Examples—Banana (classed as a berry).
Apple (classed as a pome).

The fruit wall is called the *pericarp.* It has three layers: the outer *exocarp,* the central *mesocarp,* and the inner *endocarp.* These layers develop to different degrees of thickness and texture in the various types of fruit.

Fleshy fruits are those in which the pericarp becomes fleshy.

Berry.—In the berry the entire pericarp is fleshy, enclosing one or more seeds.

In some the exocarp forms a thin outer layer, the *skin.*

Examples—Grape, currant, tomato, date, blueberry.

In some the exocarp forms a hard rind.

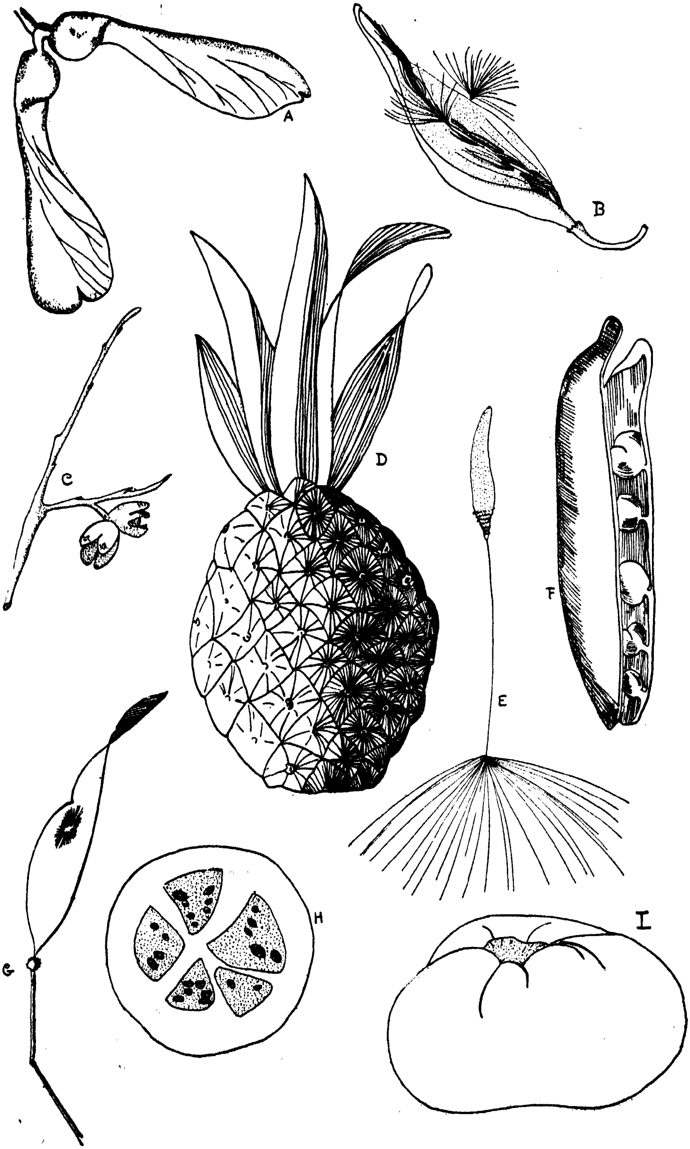


Fig. 248.—Types of fruits. *A*, Samara (Maple) ; *B*, follicle (Milkweed), *C*, capsule (Witch-hazel) ; *D*, a multiple fruit (Pineapple) ; *E*, akene (Dandelion) ; *F*, pod (Pea) ; *G*, samara (Ailanthus) ; *H* and *I*, berry (Tomato). (Drawn by Nancy ~~You~~ngman.)

Examples—Squash, cucumber.

In others it forms a leathery rind.

Examples—Orange, lemon, grapefruit.

Drupe.—A drupe is a form of fruit in which the endocarp forms a stone, the outer layers becoming fleshy.

Examples—Cherry, peach, almond, olive, and the separate fruits of the raspberry and blackberry.

Pome.—A pome is a form of fruit in which the receptacle has grown up and surrounded the carpels, forming with the outer layers of the ovary wall a fleshy pulp. The central part of the fruit consists of the basal portions of the carpels which with a leathery endocarp forms the core. Each carpel contains two or more seeds.

The carpels are completely surrounded by and united with the receptacle which forms the skin and the greater part of the fleshy pulp. The ovary wall contributes to the inner portion of the pulp.

Examples—Apple, pear.

Dry fruits are those in which the pericarp is dry. Forms which split open when ripe are said to be *dehiscent;* the others, *indehiscent.* The number of carpels varies, as do the lines of dehiscence. If it occurs along the lines of fusion between carpels where the seeds are arranged, the dehiscence often scatters the seeds to some distance.

Dehiscent types:

Pod. Examples—Bean, pea.
Follicle. Example—Milkweed.
Capsule. Examples—Lily, poppy.

Indehiscent types:

Grain. Examples—Wheat, barley, corn.
Akene. Examples—Sunflower, buttercup, strawberry.
Samara. Example—Maple (winged).
Schizocarp. Examples—Carrot, nuts.

CHAPTER XXIII

CLASSIFICATION OF PLANTS

Phylogeny

The origin of the spermatophytes from a common ancestral stem in the Cycadofilicales has been discussed in the previous chapter. The phylogenetic tree represented in Fig. 249 has been constructed to represent the prevailing theories, although it must be borne in mind that much doubt still remains as to the exact identity of the connecting groups.

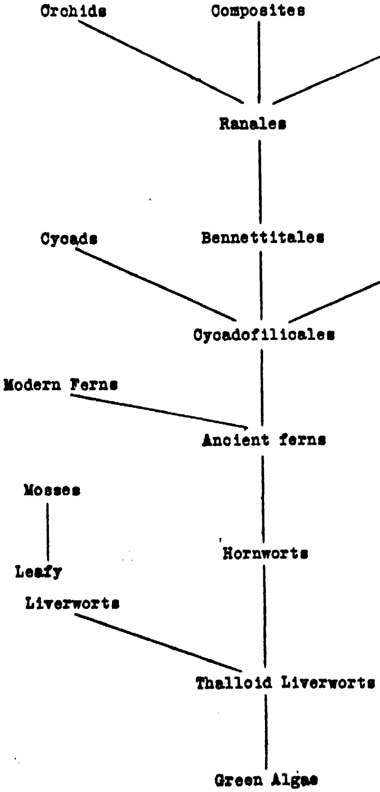


Fig. 249.—Diagram to illustrate the relationships of the higher plants.

As shown on the chart, the Ranales are the group of flowering plants most resembling the cone structure. The woody representatives of the group are the magnolias. The buttercups are herbaceous. The woody groups are the primitive ones, and this resemblance of the buttercups to the magnolias points to an early differentiation of the herbaceous structures from the woody ones.

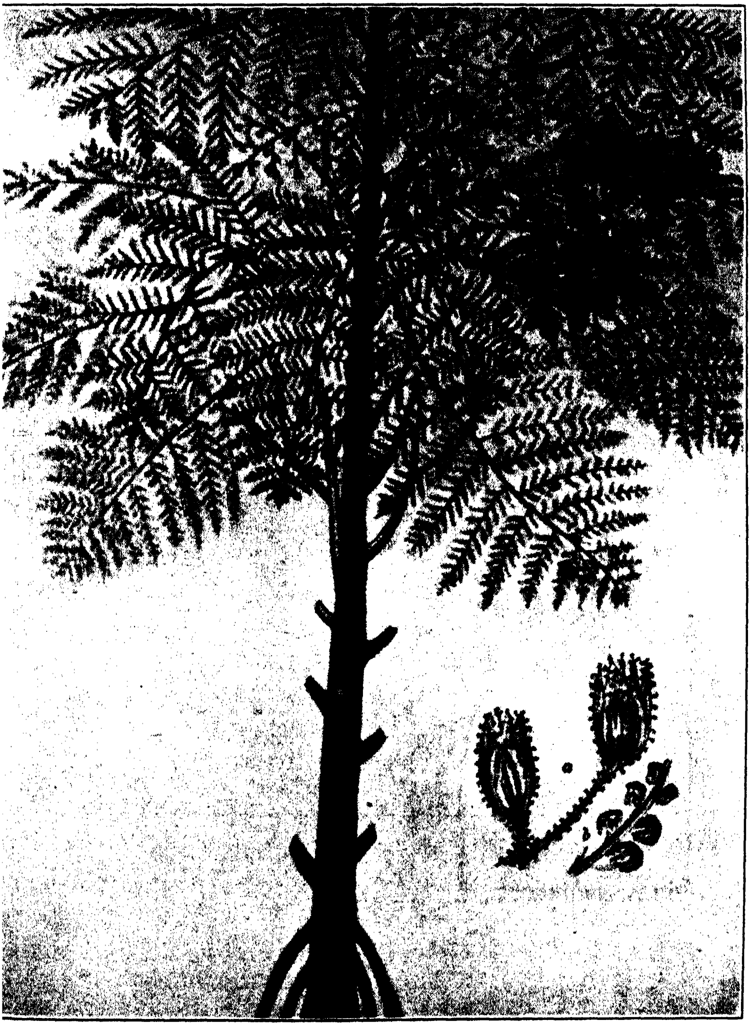


Fig. 250.—Restoration of a carboniferous seed fern *(Lyginodendron oldhamium)*. (After Scott.) (Reprinted by permission from Plants of the Past, by Knowlton. Published by Princeton University Press.)

The union of the macrosporophylls and the microsporophylls on one peduncle was first indicated in the Bennettitales (see page 376). The microsporophylls become the stamens which form in whorls around the terminal macrosporophylls that form the pistil. Fig. 252 indicates the relationships of the flowering plants according to the Besseyan system, which recognizes the dicotyledons as the primitive group, with the spiral arrangement of the floral parts preceding all others. This system was first suggested in 1895, but was finally worked out in its present form in 1915.

Fig. 251.—Blossom of the tulip tree. A representative of the Magnolia family, the woody perennials of the order Ranales. Shows the primitive flower arrangement. (Photograph by M. C. Dickerson. Courtesy of the American Museum of Natural History.)

The chart, which is based on the plan first used by Clements, shows the three main lines of development from the buttercups with their side branches. The flower formula in each case interprets the floral arrangement of the group, and the dividing lines make of the chart a working key from which any flower with known floral arrangement can be placed in its family.

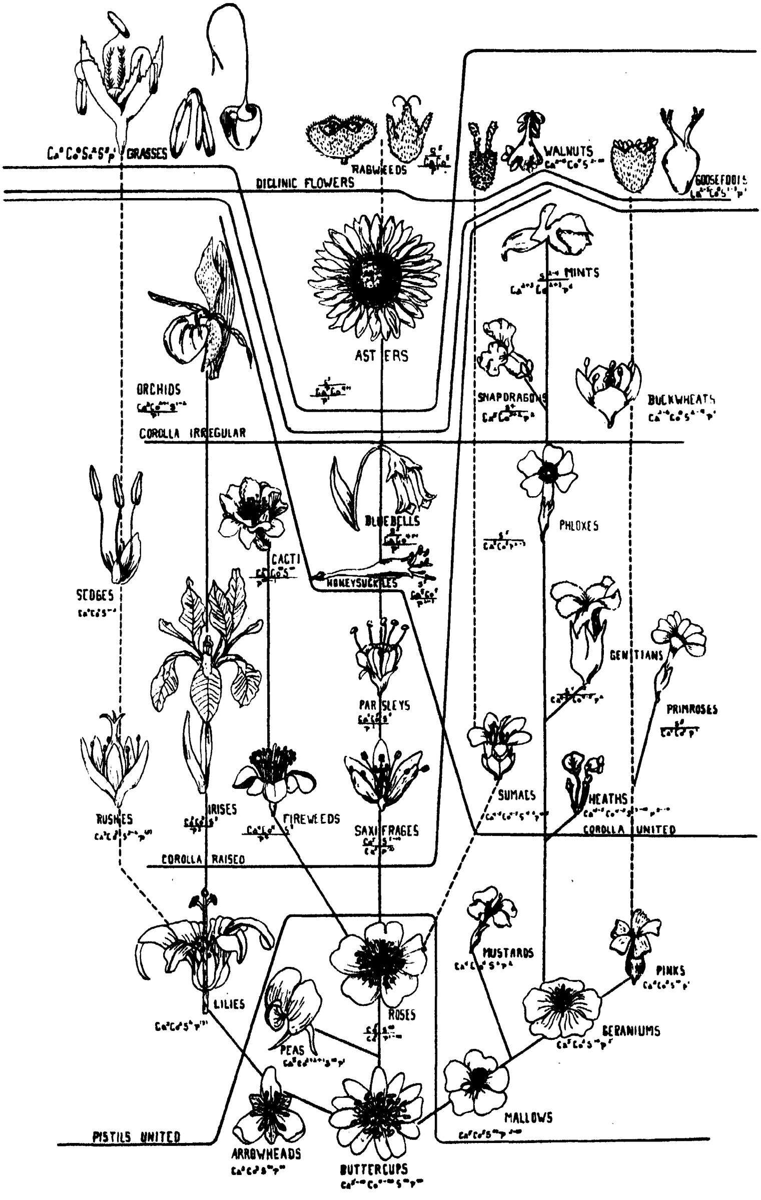


Fig. 252.—Chart showing the relationships of the flower families. (Adapted from the chart in Clements and Clements: Flower Families and Their Ancestors, H. W. Wilson Co., New York.) (Drawn by Louise Peebles.)

The symbols used in the floral formula must be understood before the key can be used intelligently. Ca is the symbol used for sepals, Co for petals, S for stamens, and P for carpels. The number of parts is indicated by the figures which follow the symbols, and the arrangement by such devices as parentheses to indicate fusion of parts, and the raising of symbols above a line to indicate the raising of one part above another on the flower.

Since the symbols on the chart are not easily followed, they are listed here in three columns for convenience.

LIST 1

Buttercups	$Ca^{3-\infty}\quad Co^{0-\infty}\quad S^{\infty}\quad P^{\infty}$
Mallows	$Ca^{5}\quad Co^{5}\quad S^{\infty}\quad P^{5-\infty}$
Geraniums	$Ca^{5}\quad Co^{5}\quad S^{10}\quad P^{5}$
Mustards	$Ca^{4}\quad Co^{4}\quad S^{6}\quad P^{2}$
Pinks	$Ca^{5}\quad Co^{5}\quad S^{10}\quad P^{1}$
Primroses	$\begin{array}{ccc} & S^{5} & \\ \hline Ca^{5} & Co^{5} & P^{1}\end{array}$
Buckwheats	$Ca^{2-6}\quad Co^{0}\quad S^{2-9}\quad P^{1}$
Goosefoots	$Ca^{2-5}\quad Co^{0}\quad S^{2-5}\quad P^{1}$
Heaths	$Ca^{4-5}\quad Co^{4-5}\quad S^{3-10}\quad P^{3-10}$
Honeysuckles	$\begin{array}{ccc} & S^{5} & \\ \hline Ca^{5} & & C^{05} \\ \hline & P^{2-5} & \end{array}$
Gentians	$\begin{array}{ccc} & S^{4-5} & \\ \hline Ca^{4-5} & Co^{4-5} & P^{2}\end{array}$
Phloxes	$\begin{array}{ccc} & S^{5} & \\ \hline Ca^{5} & Co^{5} & P^{2-3}\end{array}$
Mints	$\begin{array}{ccc} & S^{2-4} & \\ \hline Ca^{2+3} & Co^{2+3} & P^{4}\end{array}$
Sumachs	$Ca^{4-5}\quad Co^{4-5}\quad S^{4-5}\quad P^{4-5}$
Walnuts	$Ca^{2-4}\quad Co^{0}\quad S^{2-\infty}$

LIST 2

Buttercups	$Ca^{3-\infty}\quad Co^{0-\infty}\quad S^{\infty}\quad P^{\infty}$
Roses	$\begin{array}{cc} Co^{5} & S^{\infty} \\ \hline Ca^{3} & P^{1-\infty}\end{array}$
Peas	$Ca^{5}\quad Co^{2+2+1}\quad S^{10}\quad P^{1}$
Saxifrages	$\begin{array}{cc} Co^{5} & S^{5-10} \\ \hline Ca^{5} & P^{2}\end{array}$
Parsleys	$\begin{array}{ccc} Ca^{5} & Co^{5} & S^{5} \\ \hline & P^{2} & \end{array}$
Bluebells ♠	$\begin{array}{ccc} & S^{5} & \\ \hline Ca & & Co^{4+1} \\ \hline & P^{1} & \end{array}$

Asters

$$\frac{S^5}{\dfrac{Ca^{p}\qquad\qquad Co^{4+1}}{P^1}}$$

Ragweeds

$$\frac{S^5}{\dfrac{Ca\qquad\qquad Co^5}{P^1}}$$

Fireweeds

$$\frac{Ca^4\qquad Co^4\qquad S^{\infty}}{P^4}$$

Cacti

$$\frac{Ca^{\infty}\qquad Co^{00}\qquad S^{\infty}}{P^{00-1}}$$

LIST 3

Buttercups	$Ca^{3-\infty}$	$Co^{0-\infty}$	S^{∞}		P^{∞}
Arrowheads	Ca^3	Co^3	S^{∞}		P^{∞}
Lilies	Ca^3	Co^3	S^6		P^3
Rushes	Ca^3	Co^3	S^{3-6}		P^3
Sedges	Ca^0	Co^0	S^{1-3}		P^1
Grasses	Ca^0	Co^0	Sc^2	S^3	P^1

Irises

$$\frac{Ca^3\qquad Co^3\qquad S^3}{P^3}$$

Orchids

$$\frac{Ca^3\qquad Co^{2+1}\qquad S^{1-2}}{P^1}$$

The Besseyan system recognizes so many structures as derived which were formerly considered primitive, that the primitive and derived conditions have been arranged in parallel columns for reference.

PRIMITIVE	DERIVED
1. Growth perennial	Growth biennial or annual
2. Trees or shrubs	Climbing plants
3. Stem woody	Stem herbaceous
4. Stem unbranched	Stem branched
5. Vascular bundles arranged in concentric rings	Vascular bundles scattered
6. Leaves simple	Leaves compound
7. Leaves solitary	Leaves many
8. Leaves arranged in spiral	Leaves whorled or opposite
9. Leaves evergreen	Leaves deciduous
10. Leaves with netted veins	Leaves with parallel veins
11. Flower solitary	Flowers many
12. Floral parts arranged in spiral	Floral parts cyclic
13. Floral parts numerous	Floral parts few
14. Petals present	Petals absent
15. Parts of perianth separate	Parts of perianth united
16. Symmetry radial	Symmetry bilateral or asymmetrical
17. Ovary superior	Ovary inferior

18. Pistils and carpels separate	Pistils and carpels united
19. Stamens numerous	Stamens few
20. Seeds numerous	Seeds few
21. Cotyledons 2	Cotyledon 1

ABRIDGED CLASSIFICATION

Plant Kingdom

In referring to the abridged classification the student must bear in mind the fact that the relationships of the thallophytes have never been satisfactorily worked out. The division into Algae and Fungi is an artificial distinction based on the presence or absence of chlorophyll. The absence of chlorophyll, except in the autophytic bacteria, must be considered a derived condition, and not all the Fungi have been derived from the same green forms. Thus the grouping of the Fungi together has no phylogenetic significance.

The red and brown algae, too, present problems, for these groups have specializations, both in tissue formation and in reproduction, which suggest the tissue plants, and may not belong with the thallophytes at all. The entire grouping, therefore, is open to question, but the terms involved are in such general use that it is difficult for new classifications to get recognition. The most widely accepted classification has been used here, and questions of relationship in the more fundamental groups are discussed elsewhere.

A few selected orders of the angiosperms have been included. Reference may be made to the chart on page 425.

Phylum **Thallophyta**—Simple plants
No definite alternation of generations

Subphylum **Phycophyta** (Algae)—With chlorophyll
Class CYANOPHYCEAE— Blue-green algae—Synechococcus
Gloeocapsa
Nostoc
Class CHLOROPHYCEA— Green algae— Chlamydomonas
Protococcus
Ulothrix
Oedogonium
Spirogyra
Class PHAEOPHYCEAE— Brown algae— Fucus (seaweed)
Class RHODOPHYCEAE— Red algae— Polysiphonia (seaweed)

Subphylum **Mycophyta** (Fungi)—Without chlorophyll	
Class SCHIZOMYCETES—	Bacteria
Class MYXOMYCETES—	Slime molds
Class PHYCOMYCETES—	Albugo (white rust)
	Mucor (black mold)
	Microsphaera (mildew)
	Penicillium (blue mold)
Class ASCOMYCETES—	Yeasts
	Peziza (cup fungus)
	Lichens (symbiotic forms)
Class BASIDIOMYCETES—	Rusts
	Puff balls
	Mushrooms
Phylum **Embryophyta**—	
Subphylum **Bryophyta**—	Thallus land plants without vascular bundles
	Intercellular air spaces
	Independent gametophyte and dependent sporophyte
Class HEPATICAE (liverworts)—	Flat thallus
	Marchantia
Class MUSCI (mosses)—	Leafy thallus
	Polytrichum
Subphylum **Pteridophyta**—	Vascular land plants
	Intercellular air spaces
	Independent gametophyte and independent sporophyte
Class FILICINEAE—Ferns	Underground stem
	Large aerial leaves
	Osmunda (royal fern)
	Pteris (brake fern)
	Aspidium (wood fern)
	Polystichum (Christmas fern)
Class EQUISETINEAE (horsetails)—	Underground stem with upright aerial shoots
	Elongate internodes, whorls of leaves at nodes
	Equisetum (homosporous)
Class LYCOPODINEAE (club mosses)—	Creeping stem
	Small, awllike leaves
	Lycopodium (homosporous)
	Selaginella (heterosporous)
Subphylum **Spermatophyta**—	Vascular seed plants
	Independent sporophyte with dependent gametophyte

Class Gymnospermae—	Cone-bearing with seeds exposed	
Order *Cycadofilicales*—	Extinct seed ferns (Carboniferous)	
	Lyginodendron	
Order *Bennettitales*—	Extinct seed plants (Mesozoic)	
	Bennettites	
Order *Cycadales*—	Extinct and modern plants	
	Massive columnar stem with whorls of leaves at the top	
	Zamia	
Order *Cordaitales*—	Extinct trees (Carboniferous)	
	Tall, slender, branching stem	
	Large pith	
	Cordaites	
Order *Ginkgoales*—	Small pith	
	Ginkgo (maidenhair tree)	
Order *Coniferales*—	Excurrent branching	
	No tracheal tubes in wood	
	Yew (seeds fleshy)	
	Pinus (seeds dry)	
Order *Gnetales*—	Tracheal tubes in secondary wood	
	Ephedra	
Class Angiospermae—	Flower-bearing with seeds inclosed	
	Tracheal tubes in secondary wood	
	(32 orders and 300 families)	
Subclass Dicotyledoneae—	Two seed leaves	
	Netted venation	
	Flowers in fours or fives or multiples	
Superorder *Strobiloideae*—	"Cone flowers"	
Order 1 *Ranales*—	Primitive group	
	Petals separate	
	Polycarpellate	Buttercups
		Magnolias
Order 8 *Ericales*—	Specialized group	
	Petals fused	
	Polycarpellate	Pinks
Order 10 *Gentianales*—	Specialized group	
	Petals fused	
	Dicarpellate	Gentians
Superorder *Cotyloideae*—	"Cup flowers"	
Order 1 *Rosales*—	Genetic group	
	Petals separate	Roses
Order 7 *Umbellales*—	Specialized group	
	Flowers in umbels	
	Petals separate	Parsleys
Order 9 *Campanulales*—	Specialized group	
	Petals fused	Bluebells

Subclass MONOCOTYLEDONEAE—	One seed leaf Parallel venation Flowers in threes or multiples	
Superorder *Strobiloideae*—	“Cone flowers”	
Order 1 *Alismatales*—	Genetic order Petals mostly separate Carpels 1-many	Water plantains
Order 2 *Liliales*—	Variated order Herbs, shrubs, trees Flowers perfect, parts in threes	Lilies
Order 5 *Graminales*—	Specialized group Flowers reduced in chaffy spikelets Perianth absent	Grasses Sedges
Superorder *Cotyloideae*—	“Cup flowers”	
Order 3 *Orchidales*—	Highly specialized group Petals fused	Orchids

PART III

PROGRESSIVE ORGANIZATION

SECTION II

ANIMAL KINGDOM

CHAPTER XXIV

ORGANIZATION

Animals with tissues are designated as Metazoa to distinguish them from the cellular Protozoa. The transition from cells to tissues can be traced in the Protozoa through the division of labor between cells and the aggregation of cells into colonies. Cells which are set apart to perform a portion of the work of the colony invariably lose in potentiality, since they no longer perform the work of the whole organism.

With the development of tissues there is still further specialization in function with further loss of potentiality in the specialized cells. In the development of the animal kingdom, therefore, progressive specialization has been accompanied by progressive loss of potentiality. This has resulted in the development of tissues and organs along a definite type of organization. The plan adopted for the study of the animal kingdom, therefore, is based on the progressive organization of the axes, the symmetry, and the germ layers.

Axes.—With the establishment of tissues, the axes of an organism become localized and graded. The protoplasm will be found to be more active at one end of an axis than at the other, and this protoplasm will tend to dominate over that of lesser activity. This grading of the energies along an axis from the more active to the less active cells is the basis of the *axial gradient theory* suggested by Child.

Symmetry.—By symmetry is meant the plan by which the energies are grouped about an axis. The grouping will be determined by the interaction of the forces exerted by the external and internal environment. The primitive arrangement of cells will be spherical, as seen in the hollow spherical colonies of the Protozoa. Here the plastic protoplasm is subjected to equal pressure in all directions, and responds equally in all directions. In such an arrangement no functional axis exists.

An attached form will be similarly exposed to equal pressure in all directions, and responds equally in all directions. The attachment, however, forms an axis around which the forces will be exerted, and the energies thus grouped around an axis will assume a radial form. This type of symmetry is found in the simple tissue animals. Active progress through the water is impossible and free swimming organisms of the radial type are necessarily slow and awkward in their movements. They usually progress backward by ejecting water forcibly from the subumbrella cavity.

Persistent pressure against the currents of water may have aided in shaping the bilateral type, for active progress through the water divides the water currents symmetrically on two sides of the organism, and the less resistance the body presents to these currents, the faster is the movement.

As the bilateral type has been preeminently successful in animals no further change in the axes has developed, but retrogression has occasionally set in with the assumption of a creeping habit, as in the snail. Here a differential growth of the protoplasm on two sides of the axis caused the body to twist into a spiral with the consequent reduction of the organs on the inner side of the spiral.

The symmetry of animals can best be observed in cross sections. A cross section is one cut through the body at right angles to the main axis. The symmetry will be seen to be bilateral if only one line drawn through the center will divide the section into two equal parts. In a radial section, lines passing from any point on the circumference through the center, will divide the section equally.

The Germ Layers.—In the early development of an animal, the cells become grouped into layers. This is the first indication of division of labor between cells. (See Chapter XIII in Part II.) In the further development of tissues they can be traced back to one of the three fundamental layers. This is the basis of the germ layer theory of Haeckel.

Ectoderm—the outer layer of cells (except in the sponges).

Endoderm—the inner layer of cells (except in sponges).

Mesoderm—a central layer which grows between the other two. When a coelom is present, it forms as a cavity in the mesoderm and is lined by a layer of epithelial mesoderm cells. A true coelom can always be detected by this lining of epithelium.

Organisms with only the first two layers are known as *diblastic;* those with three layers, as *triblastic.* According to this plan, the animal kingdom is presented under the following headings:

Radial Organization—Coelenterates and Sponges
Bilateral Organization—Flat Type of Flatworms
Bilateral Organization—Round Type of Roundworms
Metameric Organization—Segmented Worms
Specialized Organization—Shellfishes and Starfishes
Advanced Organization—Prochordates and Vertebrates.

RADIAL ORGANIZATION

The radial forms are diblastic. No anterior end is established, but an oral-aboral axis exists around which the energies are grouped equally, forming innumerable radial axes.

There are two radial groups, the sponges and the coelenterates, which are believed to have had separate origins from the flagellated Protozoa as shown in Fig. 97. These groups differ radically in that the arrangement of the two germ layers is reversed. In the Coelenterata, which are the successful forms, the ectoderm is on the outside, the endoderm lining the digestive tract. In the sponges the endoderm is on the outside, the flagellated ectoderm cells lining the digestive cavity. For this reason it is customary to designate the layers in sponges as the dermal and gastral layers to avoid confusion.

No other animals have developed with an arrangement of cells similar to that of sponges, so that this group marks the end of a line. The coelenterate arrangement was the successful one, therefore, since from it all higher animals have developed.

COELENTERATES

Coelenterates are typically diblastic animals with radial symmetry and a blind digestive cavity. Between the two germ layers, the ectoderm and the endoderm, is a secretion of jelly-like material formed by the cells of both layers, the *mesoglea*. The thickness of the jelly varies according to the type of individual. It is thickest in the large marine jellyfishes.

There is typically an alternation of generations with asexual and sexual individuals. The asexual form is a *polyp,* which reproduces by budding. The sexual form is a *medusa,* which produces gametes. The medusa is the form known popularly as the jellyfish.

The life cycle varies so greatly within the phylum and so consistently with the changing structure that it can be used as a basis of classification. In the Hydrozoa both polyp and medusa stages are found, but the alternation is not always complete. The polyp is the dominant form, and the colonies are typically small. In the Scyphozoa the medusa dominates, and the alternation is reduced. In the Anthozoa the medusa stage is entirely absent. The polyps are specialized and frequently form corals. The colonies are large and cumulative, the new forms growing on the skeletons of the old until coral reefs are formed.

The main types of life cycle within the phylum are represented by the formulas given below.

Hydrozoan Types

Hydra: Polyp—bud—polyp—germ cells—fertilized egg—polyp.

Obelia: Colony—blastostyle—medusa—germ cells—fertilized egg—colony.

Gonionemus: Medusa—germ cells—fertilized egg—reduced polyp—medusa.

Scyphozoan Type

Aurelia: Medusa—germ cells—fertilized egg—scyphistoma (reduced polyp)—strobila (reduced colony)—ephyra (young medusa)—adult medusa.

Anthozoan Type

Coral: Polyp—bud—polyp—germ cells—fertilized egg—polyp.

A HYDROZOAN POLYP

Hydra

Hydra is a small, fresh water form frequently found in the floating green scums. There are two common species: *Hydra viridis*, the green form, and *Hydra fusca* (or *oligactis*) the

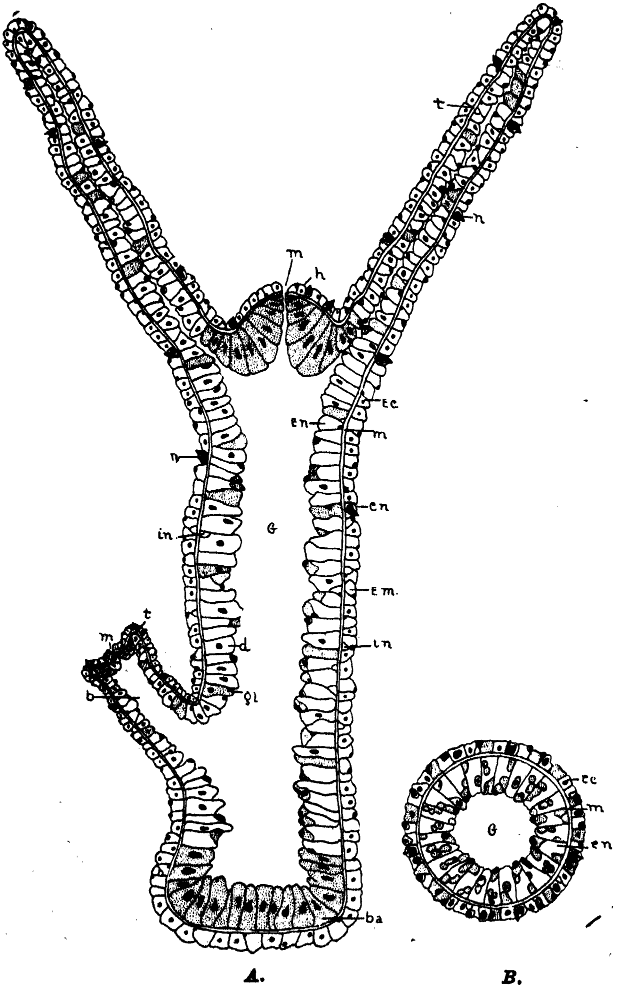


Fig. 253.—*A*, Hydra. Longitudinal section. *t*, Tentacle; *n*, nematocyst; *m*, mouth; *h*, hypostome; *ec*, ectoderm; *en*, entoderm; *M*, mesoglea; *G*, gastrovascular cavity; *e.m.*, epitheliomuscular cell; *in*, interstitial cell; *cn*, cnidoblast; *d*, digestive cell; *gl*, glandular cell; *ba*, basal disc; *b*, bud. *B*, Hydra, cross-section. (Drawn from a slide by Catherine Sloan.)

brown, transparent form. The color in the green Hydra is not due to pigment in the cells of the animal but to a species of Alga which lives in the cells of the Hydra. This is a case of *symbiosis.* The green plant undoubtedly makes use of the carbon dioxide excreted by the Hydra and is thus directly benefited in its photosynthesis. The Hydra is also benefited by the arrangement in some obscure way, and may make use of the oxygen liberated by the plant, since it will live longer in an atmosphere devoid of oxygen than will a brown Hydra.

The Hydra is usually found attached by the *basal disc,* with the *tentacles* extended. These are instantly withdrawn, however, when disturbed, demonstrating the extreme sensitivity of the cells. The *mouth* is on the tip of the *hypostome,* which is surrounded by a ring of tentacles, an arrangement which immediately suggests the radial symmetry of the organism. The tentacles are the only structures which can rightfully be called organs. In general, the Hydra is an organism of tissues, composed of two layers of cells; the outer ectoderm, and the inner endoderm. Between the two cell layers there is a noncellular secretion formed by the cells of both layers.

The axis runs from the mouth to the basal disc. The gradation of energies is generalized, but some dominance of the nerve cells which are concentrated around the mouth, is established. Subsidiary axes radiate from the center equally in all directions.

Tissue organization is also generalized. Some types of cells are limited to the ectoderm, some to the endoderm, but there are others which are formed equally well by both layers. The cells are limited in function, but are not joined together into definite tissues, and bear no resemblance to organs.

Cells Found Only in the Ectoderm

1. **Epitheliomuscular Cells.**—There are no cells exclusively muscular in function, but the epithelial cells possess contractile processes, *myofibrils,* at the base. These run in an anteroposterior direction, and, together with the transverse fibers found in the endoderm, give it the possibility of expanding and contracting the cylinder. The cells of the basal disc also have the power of attachment by pseudopodial movement.

2. **Nematocysts.**—These cells are products of the small formative cells found in both the ectoderm and endoderm. They are peculiar to the

coelenterates, although the trichocysts of Paramecium are analogous structures. When first formed they are *cnidoblasts,* but on further modification they become stinging cells with a thread coiled tightly within a capsule in each cell. The thread often extends slightly into the surrounding medium.

Upon stimulation, these threads are discharged as by a pull of a trigger, and a minute drop of poison exudes from the end. By this means enemies larger than the Hydra are stung and become defenseless before it. They are the only means of protection in the coelenterates and are used for both offense and defense. They are found all over the body except on the basal disc, but are particularly abundant on the tentacles and about the hypostome.

3. **Reproductive cells.**—The germ cells are also products of the formative cells. Since Hydra is hermaphroditic, it produces both male and female cells in the same individual. This is not unusual in the lower organisms. When immature, the two sexes cannot be distinguished; but upon maturity, the egg cell absorbs all the material of the surrounding protoplasm into one large cell, and the sperm cell divides into countless minute, nucleated cells.

Cells Found Only in the Endoderm

1. **Nutritive-muscular cells.**—These are flagellated cells, the flagella extending into the digestive cavity. They are larger than the epitheliomuscular cells, and the contractile fibers at the base run at right angles around the body. Their contraction elongates the body.

The cytoplasm of these cells is highly vacuolated, and, after feeding, contains many food substances which are taken in by pseudopodial movement at the free end. In *Hydra viridis,* the symbiotic Algae live in these cells.

2. **Slime cells.**—These cells are filled with granules which, on discharge, liberate a slime. They are most abundant in the mouth region, and are of short, cylindrical shape, lying between the nutritive-muscular cells.

3. **Albumen cells.**—These are much like the slime cells but the granules of secretion are larger and they usually possess two or three flagella. They are widely distributed, and each cell has a thin process at the base attached to the mesoglea.

Cells Found in Both Ectoderm and Endoderm

1. **Nerve cells.**—The nerve cells are the most highly differentiated cells in the coelenterates, being specialized for the sole function of conduction. All cells of Hydra are irritable, but the nerve cells take the stimuli from the *epitheliomuscular* cells and other sensitive cells and conduct them to the muscle fibers. They form an interlacing network around the organism, but are more numerous in the region just surround-

ing the mouth. They are both bipolar and multipolar in form, with fine processes extending into the protoplasm.

Nerve cells are more numerous in the ectoderm than in the endoderm, and their concentration into a ring around the mouth is in keeping with the axial gradient theory. In all animals, the tissues of greatest activity are those of the nervous system, and the tendency toward concentration at the anterior end is one of the first indications of cephalization.

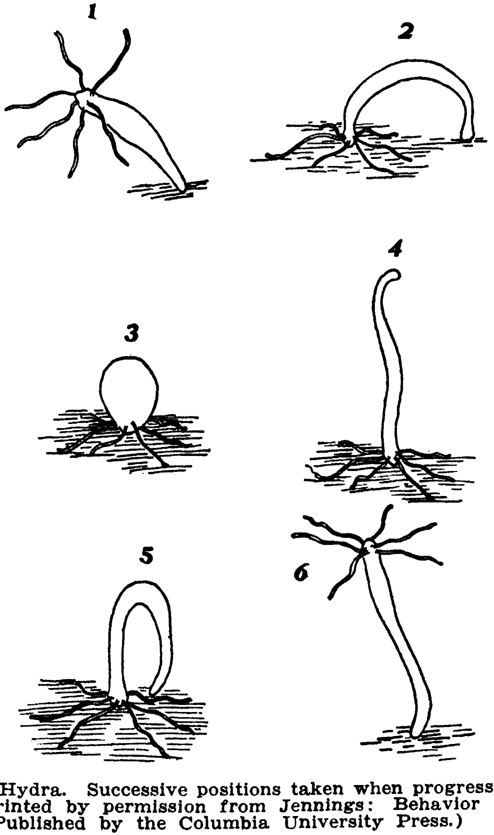


Fig. 254.—Hydra. Successive positions taken when progressing by somersaults. (Reprinted by permission from Jennings: Behavior of the Lower Organisms. Published by the Columbia University Press.)

2. **Sensory cells.**—Cells specialized for receiving stimuli will be found in the anterior end. Being slender cells, pushed in between epithelial cells, they send out branching fibers from the base which connect them with both nerve and muscle cells. They are more numerous in the endoderm than in the ectoderm.

3. **Interstitial cells.**—Small, round *formative* cells are always found, chiefly in the region of the hypostome, pushed in between the epithelial

cells and the mesoglea. These are the cell reserves, replacing other types of cells when they are exhausted. They are more abundant in the ectoderm. They constitute an undifferentiated and generalized tissue from which the whole Hydra can be replaced. It is due to these cells that very small portions of a Hydra can regenerate the whole animal.

Behavior

Hydra reacts to its external environment much as does the Paramecium. If it has been deprived of food for any length of time, active movements will occur. The Hydra alternately expands and contracts in all directions; the expansion is a prolonged act, the contraction is sudden and of short duration.

It may slide on the basal disc for some distance and repeat the movements, or it may turn completely over by the somersault method, attaching the tentacles to the disc, releasing the basal disc, and drawing it up to the tentacles by contraction. Then, by a similar movement, the body is elongated, the basal disc is attached to the glass on the opposite side, and the tentacles are retracted. Sometimes the action is quite rapid, and if no food is found, the Hydra will finally contract into a ball as if disgusted, and refuse to move.

Food is grasped by the tentacles and passed into the mouth cavity. The Hydra will continue to feed until to seems about to burst. The normal food of Hydra is small animals, but it is often known to gorge itself and ingest articles of food many times its size. Ordinarily the discharge of nematocysts accompanies the stimulus of food, the prey being stung and ingested at leisure. Carbohydrate food evokes no such reaction, and starch granules fed to a Hydra will be egested. The reaction to food is a positive *chemotropism.*

A negative *thigmotropism* is very marked. The slightest jar will cause the whole Hydra to contract into a ball. If one tentacle is touched, others will respond, showing that the stimulus is conducted from one spot to another over the nerve network.

In dishes standing near a window, the specimens will be found on the side toward the window unless the light is too bright, for, like the Protozoa, there is a condition of optimum illumination and one of optimum heat. *Hydra viridis* is more definitely phototropic than the brown species, due to the chlorophyll of the symbiotic Algae.

SUMMARY OF THE PHYSICAL FUNCTIONS

Sensation: Sensory cells.
Conduction: Nerve network.
Locomotion: Muscular fibers on the epithelio- and nutritive-muscular cells.
Protection: Nematocysts.

Nutrition

Digestive enzymes are found in the mouth cavity of Hydra, the cells secreting them being limited to the mouth region. Another method of digestion exists, however; materials are often drawn into the cells by pseudopodial action. In that case, intracellular digestion takes place as in the Protozoa. This is a method known as *phagocytosis* and is the same method as that used by the white blood corpuscles in ingesting bacteria.

Since every cell of the endoderm comes in contact with an ectoderm cell, absorption takes place readily and no circulation is necessary to carry the food to the cells. The movement of the protoplasm keeps it in motion, and it is passed from cell to cell by osmosis.

All cells of the ectoderm come in contact with the water and respiration takes place by diffusion through any of them; excretion of the nitrogenous waste takes place in the same way. Since the digestive tract has but one opening, the undigested food is egested through the mouth.

SUMMARY OF CHEMICAL FUNCTIONS

Digestion: Blind digestive tract, lined by flagellated nutritive cells. Phagocytosis, enzymes.
Absorption: By diffusion through the cell walls.
Circulation: No system, protoplasmic movement.
Respiration: Diffusion through ectoderm cells.
Excretion: Diffusion through ectoderm cells.

Asexual Reproduction

Like the Paramecium, Hydra has two methods of reproduction, asexual and sexual, but does not have true alternation of generations. Its cycle, therefore, bears the same relation to the cycles of the coelenterates which do have true alternation, as that of Paramecium bears to the cycles of the rest of the Protozoa.

Hydra reproduces asexually by budding instead of fission. An entire individual grows off from the side of the body. It first appears as a slight bulge in the body wall, usually quite close to the base, and both ectoderm and endoderm cells grow out into the knob. A circlet of short, blunt tentacles appears at the distal end, and the cavity of the parent is continued into the bud and into the tentacles. When complete, the bud breaks off, and the proximal end closes over to form the basal disc. Two or more buds may appear on the same Hydra, and, occasionally, buds appear on the side of the bud itself.

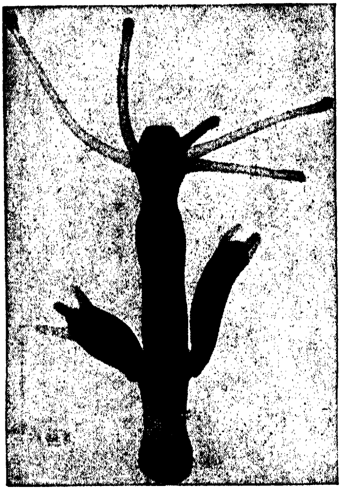


Fig. 255.—Hydra. Photograph of expanded specimen with buds. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

In this respect, also, the Hydra agrees with Paramecium, in that each individual separates from every other. In the colonial coelenterates, the buds remain attached to a main stalk, and treelike colonies may be formed. In the corals the branching oftens develops to such an extent that coral reefs are formed.

Each bud is known as a *polyp*. The sexual individual when formed is a *medusa*. If the medusa is formed, a true alternation of generations exists. All gradations of the life cycle are found in the Coelenterata from those which have no medusa to those in which the medusa is the main organism, and the polyp is reduced to a larval condition.

Sexual Reproduction

In Hydra both male and female organs may appear in the same individual, a condition known as hermaphroditism. The male organs appear near the base of the tentacles, the female organs near the basal disc. Technically, these cannot be designated as organs, but as groups of formative cells.

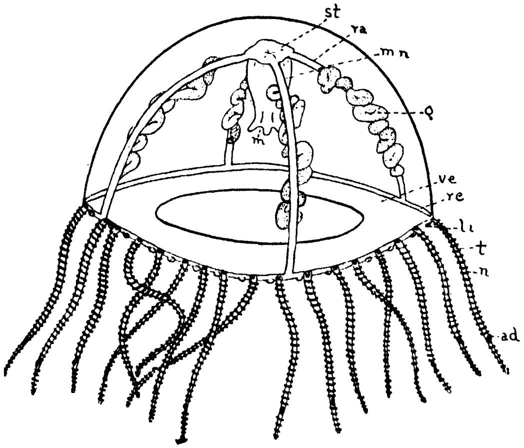


Fig. 256.—Gonionemus. *st*, Stomach; *ra*, radial canal; *mn*, manubrium; *m*, mouth with lips; *g*, gonads; *ve*, velum; *rc*, ring canal; *li*, lithocyst; *t*, tentacle; *n*, nematocysts; *ad*, adhesive pad.

Male Cells.—The male germ cells develop from the formative cells of the ectoderm. Collecting between the epitheliomuscular cells, the sperm mature by a process of reduction very similar to that of higher forms. The ripe spermatozoa are released into the water by rupture of the cysts. They consist of a head, which contains the nucleus, and a tail, which acts as a flagellum. They are extremely minute, but very active.

Female Cells.—A Hydra never develops more than one egg. The ovary develops from the formative cells which divide and produce several potential egg cells. The one which develops devours the rest, ingesting them by means of pseudopodia and absorbing them into its own protoplasm. This insures the proper nourishment of the embryo, the material absorbed being stored in the form of yolk spheres. The size of the egg, therefore, is relatively large.

When ripe, the surrounding cells of the ovary break, a sperm forces its way in, and development of the egg begins inside the ovary. When division has taken place to the extent of forming a hollow ball of cells, certain cells migrate into the hollow cavity and fill it up, thus forming the two layers of the Hydra. The ectoderm then secretes a horny layer about the embryo, and it drops off the adult Hydra and sinks to the bottom of the pond, usually resting there until the next spring when the shell will break, and the embryo will escape, develop tentacles, and assume the adult form.

A HYDROZOAN MEDUSA

Gonionemus

Gonionemus is a typical sexual individual and therefore illustrates the structure of the medusa. The medusa form is that of the organisms familiarly known as the jellyfishes, the difference in bulk being due to the great increase of mesogloea.

The aboral surface is extended over the mouth like an upturned saucer, and is called the *umbrella*. The aboral side of the umbrella is called the *ex-umbrella*, the oral side, the *subumbrella*.

The subumbrella is partly closed by a thin layer of tissue, called the *velum,* which is stretched over the opening. The medusa moves by drawing water into the subumbrella cavity and forcing it out through the narrow opening in the velum. Contraction of the entire umbrella occurs, and the force exerted by the stream of water causes the medusa to move backward. This is a slow and awkward means of progression, due to its radial symmetry.

The mouth is at the tip of the *manubrium* which hangs down into the subumbrella cavity. It opens into a *gastrovascular cavity,* consisting of a *stomach* and four *radial canals.* These are joined together by a *circular canal* which passes around the circumference of the umbrella. The digestive tract thus formed does not differ from that of the polyp, except that it is more branched to accommodate the enlarged area of cells. The only opening is the mouth.

A HYDROZOAN COLONY

Obelia

Where colonies are formed, a division of labor between polyps exists. Obelia forms a typical colony with *vegetative*

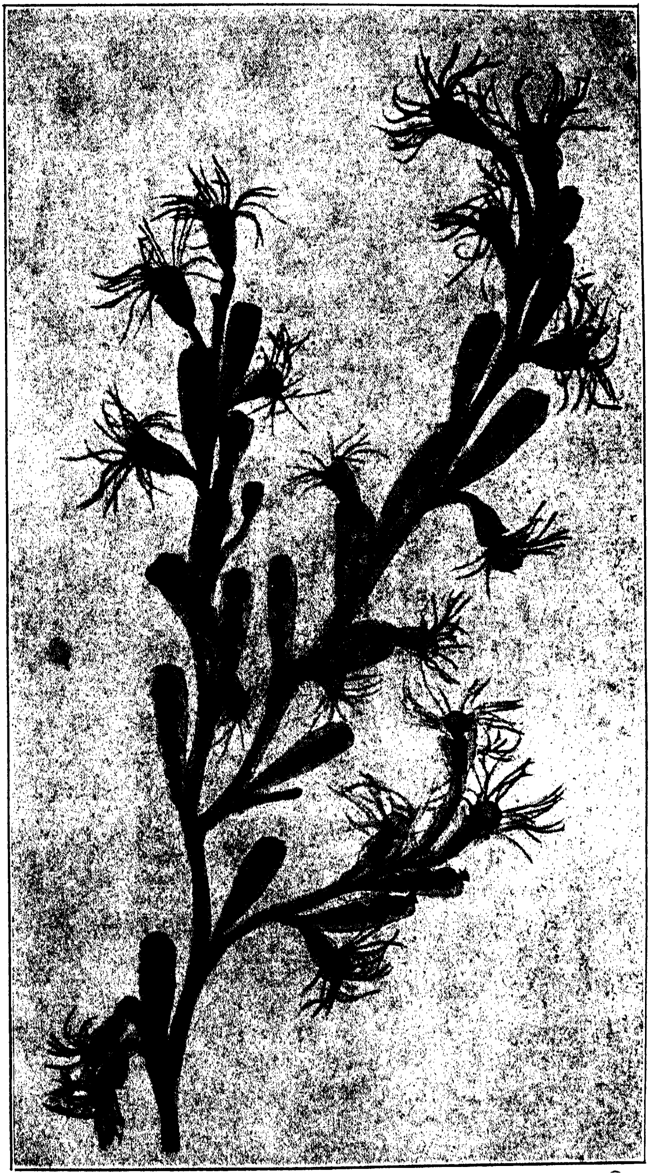


Fig. 257.—*Obelia gracilis.* Photomicrograph showing vegetative and reproductive polyps. The perisarc is shown to be continuous with the hydrothecae and gonothecae, and medusa buds are shown on the blastostyles of the gonangia. The colony develops from an egg produced by such a medusa. (Photomicrograph by Albert E. Galigher.)

and *reproductive polyps*. The branching stalks are a delicate white, giving a lacy appearance to the colony.

The stalks are surrounded by a chitinous secretion, the *perisarc,* which is continued up around each vegetative polyp to form a cup-shaped *hydrotheca.* The reproductive polyps appear on separate branches, and are called *gonangia.* These have a central axis, the *blastostyle* and are surrounded by *gonothecae.*

The medusae bud from the blastostyle and are liberated when mature. The medusae are similar to Gonionemus in form, but are very minute. The sexes are separate, and fertilization takes place in the water. The fertilized egg grows into a branching colony.

A SCYPHOZOAN MEDUSA

Aurelia

Aurelia is a medusa of the Scyphozoan type. It is one of the common large jellyfishes of the Atlantic coast. There is no velum, and the umbrella is flat and saucer-shaped. The margin has eight shallow lobes and is fringed with a circlet of small tentacles. In each lobe lies a sense organ, the *tentaculocyst,* which is believed to be an organ of equilibrium. Each tentaculocyst is surrounded by small lobes of tissue, two lateral *lappets,* and an aboral *hood,* and embedded in each is a pigment spot, the *ocellus,* which is sensitive to light.

The mouth opening is square and has four long, folded, oral arms which hang down into the water. There is a short gullet and a four-sided stomach with four gastric pouches, one from each side. These pouches contain the gonads and a few short filaments bearing nematocysts.

There are sixteen radial canals, eight unbranched and eight branched. The unbranched canals are *adradial.* They lead from the gastric pouches to the circular canal around the circumference of the umbrella. The branched canals are of two kinds, *perradial* and *interradial.* These lead from the circular canal to the grooves in the oral arms.

Thus the path of the water circulating through the medusa is diverted, and the return route is not the same as the entering route, though the mouth is the only external opening.

The alternation of generations is a reduced type. The gametes escape from the mouths of the male and female individuals, and fertilization occurs in the water. The zygote develops into a reduced polyp, the *scyphistoma,* which is not unlike a Hydra polyp. This polyp buds transversely to produce a series of saucerlike discs by a process known as *strobilation.* The *strobila* thus formed is a reduced colony. Each disc eventually develops tentacles and swims away as an *ephyra,* which is a minute medusa. This gradually develops into an adult jellyfish like the parent. See Fig. 258.

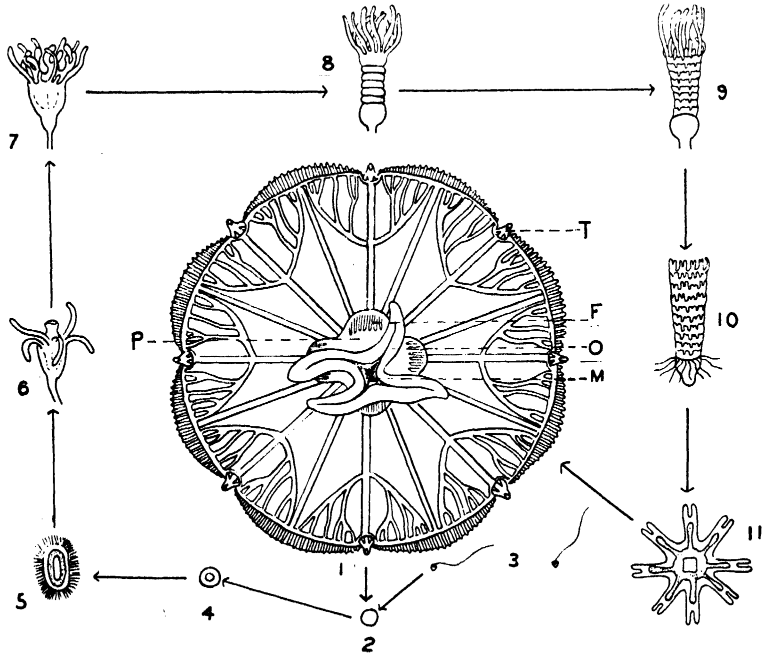


Fig. 258.—Life cycle of *Aurelia aurita.* *1,* Adult medusa; *T,* tentaculocyst; *F,* gastric filaments; *O,* oral arm; *M,* mouth; *P,* gastric pouch; *2,* egg; *3,* sperm from separate adults; *4,* zygote; *5,* planula larva; *6, 7,* stages in the development of the scyphistoma; *8, 9, 10,* stages in the development of the strobila; *11,* ephyra.

AN ANTHOZOAN POLYP

Metridium

The familiar sea anemone of Atlantic waters is Metridium. It is a polyp of the Anthozoan type and differs from the Hydrozoan polyp in having an enlarged gastrovascular cavity with *mesenteries,* forming complete or partial partitions from the body wall to the short gullet.

The contractile tentacles are arranged in circles around the slotlike mouth. When extended, a flowerlike effect is noticeable. (See Fig. 259.) The mouth leads into a short gullet, the *stomodaeum,* on each side of which is a ciliated groove, the *siphonoglyph,* down which a constant stream of water is slowly propelled to the gastrovascular cavity. Six pairs of thin double partitions divide the cavity. These are the *primary mesenteries.* They have minute holes, or *ostia,* through which water passes from one chamber to another.

Fig. 259.—Sea anemones with tentacles expanded. (Photographed from life by M. C. Dickerson. Courtesy of the American Museum of Natural History.)

From the body wall, additional partial mesenteries extend short distances into the cavity. These are the *secondary* and *tertiary* mesenteries. In cross section the arrangement of the mesenteries can be seen to be regular, and the number of the partial mesenteries to be related to that of the primaries. On each mesentery is a band of retractor muscle tissue. The bands on pairs of mesenteries face each other, except those of the pairs opposite the siphonoglyphs. These face away from each other and are known as the *directives.* The presence of the siphonoglyphs gives a ventrodorsal axis to the cross sections, thus obscuring the radial symmetry.

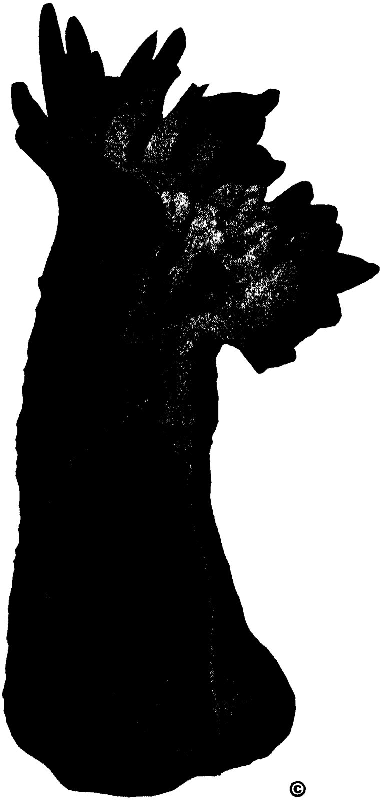


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Fig. 260.—***Metridium dianthus.*** Longitudinal dissection of a minute expanded sea anemone as it appears under the 32 mm. objective, showing the mesenteries which extend into the gastrovascular cavity, and the threadlike acontia which can be protruded through minute holes in the body wall, and which serve as organs of offense. Gonads are also shown on the edge of the mesenteries. The structure of this polyp is of the Actinozoan type. (Photomicrograph by Albert E. Galigher.)

Below the stomodaeum, the mesenteries do not close the cavity and on their inner edges are *filaments,* which have a secretory function, providing the enzymes for digestion.

Near the base of the filaments are long white threads, the *acontia,* which are provided with gland cells and nematocysts.

These can be extruded through minute pores in the body wall and are used for defense.

The gonads also lie on the mesenteries in a position parallel to the filaments. The sexes are separate and development into new polyps is direct. Asexual budding occurs near the basal disc. Metridium is a solitary polyp, but the majority of the Anthozoan polyps form colonies. The stony and horny corals are members of this group.

Corals.—In the stony corals a deposition of calcium salts in the exoskeleton gives the stony texture. The ectoderm of the basal disc secretes a calcareous cup, which is divided into chambers by radial septa between the mesenteries of the polyp. The cup thus forms an exoskeleton around which the protoplasm of the living polyp is spread as a thin film. The tentacles can be retracted into the calcareous cup for protection. The exoskeleton is continuous from polyp to polyp through the basal discs, so that massive formations can be built up. In the more complex forms the partitions between the calcareous cups may be broken down, leading to the meandering type of the brain coral. Coral reefs are the result of many generations of colonies built one upon another, the calcareous exoskeleton persisting as a foundation for the later generations of living polyps.

The horny corals have no calcareous material, but have spicules deposited in the mesoglea and occasionally have an accessory ectodermal skeleton. The corals of this group include the flexible sea fans and sea pens with the horny axial skeletons, and the precious coral from which jewelry is made.

The polyps of this group have only eight mesenteries and one siphonoglyph. The mesenteries are not in pairs and the muscle bands, therefore, face ventrally except for the directives which face away from each other as in Metridium.

COELENTERATES AT HOME

Coelenterates are among the most beautiful of Nature's products. This is due to their transparency and delicate colorings, especially in the colonial forms which often resemble delicate flowers (see frontispiece).

Whole gardens of delicate organisms can be seen on wharf piles, or on coral reefs. A glass-bottomed pail will so smooth the surface of the water that one can see for thirty feet below as though through a window pane. Flowerlike colonies with pink, white, or orange polyps can be seen waving back and forth as the water currents change. In among them are sea anemones, resembling some rich variety of chrysanthemum, cautiously extending their delicate tentacles, only to withdraw them suddenly as a crab walks sidewise across them. Retracted, the sea anemone is nothing but a brown, shapeless mass, no more attractive than the leathery tunicates which form the bulk of their neighbors. The tunicates, while the least attractive of the wharf pile group, are perhaps the most

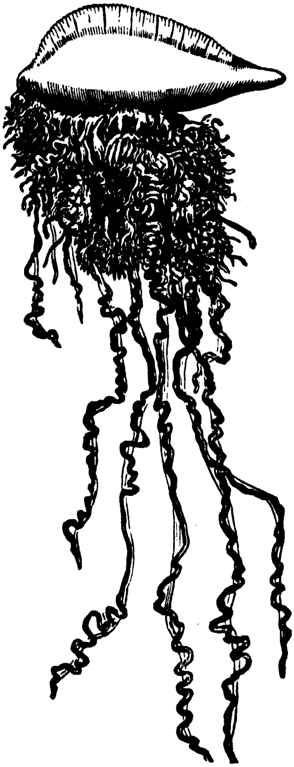

Fig. 261.—Physalia, the Portuguese man-of-war. (Reprinted by permission from Hegner: College Zoology. Published by The Macmillan Co.)

successful of the organisms seen; for these are not coelenterates, but animals of such high organization as to be grouped with the prochordates, as ancestral vertebrates.

Often in tropical waters whole bays will be covered with small sea anemones, forming a carpet across which animals may walk as on velvet. As the unwary visitor, possibly a crab, touches the delicate tentacles, they retract, but slowly expand as the animal passes on. Often the tentacles catch some minute organism and the retraction of the tentacle draws it in toward the mouth where currents set up by cilia carry it slowly but inevitably to the stomach.

Steamships frequently pass groups of the large medusae with orange and red gonads showing through the transparent umbrella. Often these have long oral arms which extend into the water behind them as they force their awkward bulk backward.

One of the most attractive coelenterates of the open ocean is the Physalia, or Portuguese man-of-war. This is a floating colony. The balloonlike float is a polyp, and its transparent reds, blues, and golds are radiant in the sunlight.

Beneath the float, there is a warlike array of polyps, which extend out through the water, often to a distance of several feet. These are the protective polyps armed with nematocysts, and poisonous secretions which are destructive to many a fish caught in their meshes. There is a small fish, however, the harvest fish, which is immune to the poison, and groups of these are often found among the tentacles, enjoying the protection of the warlike colony.

Vegetative and reproductive polyps are also found beneath the float, so that this colony represents an extreme division of labor.

Where the coral islands form, a still more riotous display of coelenterates can be seen. On the outskirts of the islands small accessory reefs are always forming and by riding over these in the glass-bottomed boats provided for tourists, one can see a whole galaxy of colors around the coral colonies. Waving sea fans; horny corals of purple and gold; long-fingered, rosy-tinted Gorgonias; sea pens and sea anemones, larger and more varied in color than in the cold Atlantic; all the varicolored and variformed colonies of branching corals, the rose, the brain, the organ pipe, and even occasionally the rosy stalks of the precious coral; all these and many more delight the eye, for this is truly Nature's garden. Nowhere in all the animal kingdom do we meet the variety and the delicacy of tint of the sessile coelenterates.

CHAPTER XXV

BILATERAL ORGANIZATION

FLAT TYPE

The next advance step in animal organization is the development of bilateral symmetry, and with it, the third germ layer. These developments were of far-reaching significance to animals, for to them is due the success of the higher groups. Bilateral symmetry is preeminently adapted to speed in locomotion, and in the third germ layer lie the foundations for greater complexity in tissue development. The organisms first reaching these attainments, therefore, form the connecting links between the radial animals and those with well-established organs and systems. There are two such connecting groups: the flatworms (Phylum Platyhelminthes), which lead direct to the segmented groups, and the roundworms (Phylum Nemathelminthes), whose affiliations lie with the unsegmented groups. In both phyla are many parasitic forms with the consequent degeneration of normal tissues, but in the free living forms, the intermediate structure is apparent.

Flatworms

The Platyhelminthes or flatworms are of simple structure: wormlike but flat like ribbons. They are widely distributed, being common in all ponds and streams, and as parasites in many animal tissues. The parasitic types show progressive degeneration and an alternation of generations, often involving a change of hosts.

ORGANIZATION

Axes and Symmetry.—It will be recalled that in Hydra only two axes exist: oral-aboral axis from the mouth to the basal disc, and the radial axes, all alike and with very little organization.

Flatworms have three: an anteroposterior, a ventrodorsal, and a bilateral axis. There is but a single line which can be drawn from the body wall through the center of any flatworm, which will divide it into two equal parts. This line establishes the ventrodorsal axis and upon it depends the whole organization of the animal, for all the organs lying along this line will be unpaired or fused, and all the organs to the side of that line will be paired, the organs on the right being mirror images of those on the left. Energy on this axis is graded from the nervous system on the ventral surface to the reproductive organs which are dorsal and lateral in position.

The anteroposterior axis is well established, and it is a significant point that the nervous system and the sensory organs have reached a forward position while the mouth remains in the middle of the ventral surface. The head of the flatworm is thus physiologically dominant over all other parts of the body.

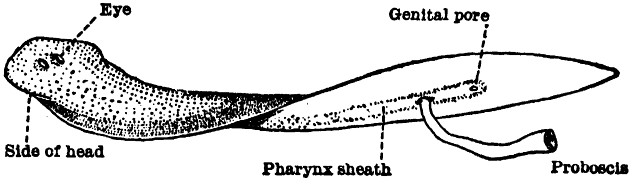

Fig. 262.—Planaria. (After Shipley and McBride.) (Repr'nted by permission from Hegner: College Zoology. Published by The Macmillan Co.)

Planaria shows clearly a tendency in the development of animals for changes in function to precede changes in structure. Thus the morphologic development has been more conservative than the physiologic, and many of the higher animals retain in their internal structure reminiscences of their ancestry, while at the same time showing great variation in the organs most closely related to function.

The statement that the mouth remains in the middle of the ventral surface is literally true, for the oral-aboral axis of Hydra corresponds with the ventrodorsal axis of Planaria. A Hydra standing on its tentacles would show the mouth in a similar position. Lang discovered that the axis of the egg of the flatworm agrees with the axis of the Hydra, the mouth forming at a point opposite the apical, or sense organ. Later, however, the whole upper pole of the egg migrates forward so that there is a shift in the axis. A lateral lobe then grows out to form the posterior end and the mouth is left in the embryonic position.

There can scarcely be any doubt, therefore, that the bilateral animals developed by a shifting of the axis, carrying the more energetic nervous tissue forward. The digestive tract is still blind, as in Hydra.

Germ Layers.—The flatworms have developed the third germ layer, the *mesoderm*. This marks the dividing line between organisms with generalized tissues, and those with definite organs, for with the development of the mesoderm comes the differentiation into organs.

The fate of the tissues of the germ layers is much the same throughout the animal kingdom. The ectoderm gives rise to the epidermal layers of the skin, to the nervous system and its derivatives, and to the sensory portion of all sense organs. The endoderm gives rise to the lining of the digestive tract and all derivatives thereof, chiefly glands in the invertebrates, and including the respiratory structures of the vertebrates. The mesoderm gives rise to all other organs; notably muscles, circulatory tissues, excretory and reproductive organs, as well as the connective tissues and mesenteries which bind all parts together.

Therefore, the tissues of greatest energy, those of the ectoderm develop first, and those of least energy, those of the mesoderm, develop last. The mesoderm of the flatworm forms a loose, spongy mass, the *parenchyma,* which fills in all the space between the organs so that they are embedded in it. The body, therefore, is solid throughout, without any coelom. Three features separate the flatworms from the higher groups: the central mouth, the absence of a coelom, and the absence of an anus.

The embedded organs are serially repeated, a condition which foreshadows the segmented, or so-called metameric structure, found in the true worms. There is no external segmentation, but the internal segmentation indicates a relation to the higher segmented groups, and together with its embryologic development, forms the basis of ~~the~~ theory that the flatworms form the stem group of the segmented or teloblast series.

PLANARIA

The Planaria has two earlike *auricles* at the anterior end which have a tactile sense; it turns its head to left and right as it moves, as though feeling its way. The two black eyespots are sensitive to light. The phototropic responses are negative, Planaria being found in dark places, under leaves and stones. Otherwise, its reactions do not differ markedly from the other types studied.

There is an organized nervous system consisting of a bilobed ganglion just under the eyespots, and connected to them and to the auricles by nerve fibers. This is called the brain and is the first indication of cephalization in animals. Two long commissures extend from these ganglia down the two sides close to the ventral surface. They pass on either side of the mouth so that some simulation of a nerve ring is retained. This is important, since the nerve ring is considered by some to be the beginning of organization in the nervous system. It is characteristic of nearly all the invertebrate groups. Cross-commissures connect the lateral ones, giving the system a ladderlike appearance.

Behavior

When the Planaria moves by the smooth gliding motion, it is using the cilia on the ventral epidermal cells. It can move equally well over the surface of the water, ventral side up, and on the surface of glass or rocks. This motion is accomplished by first secreting a mucus from the glands at the anterior end of the ventral surface, thus forming a substratum across which the cilia at the posterior end move by a backward sweep. Thus the apparent lack of effort in the gliding motion.

The Planaria can move by active muscular motion also. When swimming in the water or when righting itself if turned over, the movements resemble a ribbon which is being coiled. There are three sets of organized muscles in Planaria. The outer, circular muscles lie directly under the epidermis. Next come the longitudinal muscles of which there are both internal and external fibers and, finally, a set of oblique muscles embedded in the parenchyma.

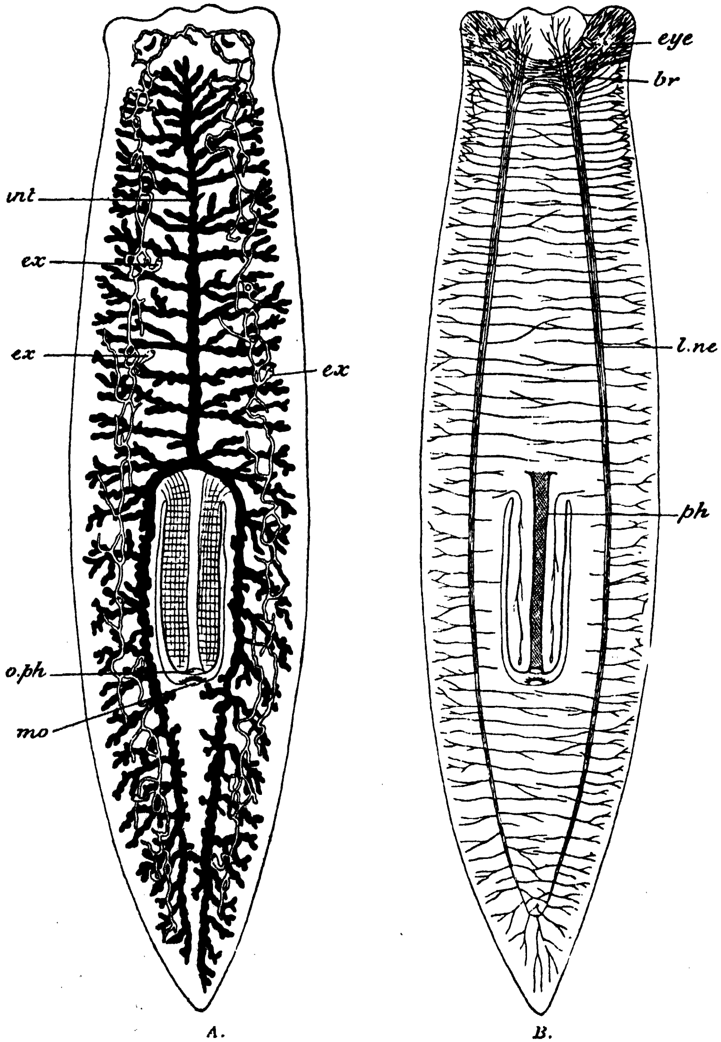

Fig. 263.—Planaria. *A*, Digestive and excretory systems; *B*, nervous system. *ex*, Openings of the excretory ducts; *int*, intestine; *mo*, mouth; *o.ph.*, opening of the pharynx; *br*, brain; *eye*, eye; *l.ne.*, longitudinal nerve; *ph*, pharynx. (After Jijima and Hatschek.) (Reprinted by permission from Parker and Haswell: Zoology. Published by The Macmillan Co.)

Planaria has strangely little protection, its habit of concealing itself under rocks probably serving in this capacity. The epidermis is ciliated over the entire body, although the cilia are more abundant on the ventral surface and especially on the posterior end. There are mucous glands which secrete the substratum on which it moves, and there are also certain rod-like bodies in the epidermis of which very little is known. It appears that these organs can be discharged to the outside when irritated, and are, therefore, probably offensive organs. The rods are called rhabdites. None of these structures, however, offer any very active protection.

SUMMARY OF THE PHYSICAL FUNCTIONS

Sensation: Two tactile auricles, two eyespots.

Conduction: Ladder type nervous system with bilobed ganglion serving as brain.

Locomotion: Three sets of muscles, longitudinal, circular, and oblique; and cilia on the ventral surface.

Protection: Rhabdites; ciliated epidermis.

Nutrition

The digestive system is not much more advanced than that of the coelenterates, having only one external opening. The tissues are more definitely established, however, and no trace of phagocytosis is found.

The pharynx is a muscular organ drawn into the pharyngeal chamber during rest. The large opening at the end of it is the mouth. While feeding, the pharynx can be protruded through a circular opening in the epidermis. Planaria can often be induced to protrude this organ as a long proboscis by placing small pieces of liver in the dish. If irritated in any way, as by a tactile stimulus, it will be immediately withdrawn.

The pharynx opens internally into a gastrovascular cavity, which branches profusely. One main branch extends forward, and two extend backward, so that by means of side branches all parts of the protoplasm are reached without any circulatory system. The undigested food is returned through the mouth as in Hydra, the digested food being absorbed where needed through the walls of the digestive tract.

The Planaria has no organs of respiration, oxygen being taken in by diffusion all over the surface. It does, however, have a definite system for removal of wastes, which is peculiar to the group of flatworms.

There are two coiled tubes running down the sides of the animal and sending out fine branches to all parts of the body. At the end of each branch is a *flame cell.* These are hollow cells into the cavity of which extend tufts of cilia, all moving in unison so as to resemble the flickering of a flame. This movement of the cilia collects the waste products and starts them down the longitudinal tube, which is an intracellular passage, the cavity of the tube passing directly through the cells instead of being lined by cells as is usual with ducts of any kind.

SUMMARY OF THE CHEMICAL FUNCTIONS

Digestion: Blind digestive tract with mouth in middle of ventral surface. Proboscis, pharynx, profusely branched intestine. Enzymes.

Absorption: Through walls of the digestive tract directly into cells.

Circulation: None, though food can be transported from cell to cell by protoplasmic movement.

Respiration: Diffusion through the epidermis.

Excretion: Flame cells and two intracellular longitudinal ducts.

Reproduction

Planaria, like most of the Platyhelminthes, is hermaphroditic, having both male and female organs in the same individual. This is the most completely differentiated system, showing that reproduction plays a far more important part in the lives of these individuals than it does in the higher forms.

Male Organs.—In Planaria, the *testes* are numerous, small, spherical bodies, scattered the entire length of the body. They are connected by tubes to the paired *vasa deferentia,* which lead direct to the median, unpaired *penis.* The penis lies inside a *penial sheath* which opens to the outside by means of the *genital pore.* Through this, the muscular penis can be everted and can be extended to such length as to permit its insertion into the genital pore of another individual. As the genital pore serves as an outlet for both sexes, the spermatozoa can be placed in the uterus of the other individual, thus insuring cross-fertilization. As the animals increase in complexity, cross-fertilization becomes more and more a necessity.

Female Organs.—There are but two *ovaries,* lying near the anterior end. Each is connected by a long *oviduct* to the median *vagina* which lies just posterior to the penis, with its opening turned forward. Thus both organs face the *genital pore.*

Numerous *vitelline glands* lie near the oviduct. These form *yolk cells* which enter the uterus with the eggs. After fertilization, a number of eggs together with several hundred of these yolk cells will be enclosed in a *cocoon,* and deposited through the genital pore upon stones or other anchorage. The yolk cells furnish ample nourishment for the developing embryos up to the time of hatching.

The multiplication of internal organs, notably those of the reproductive system, foreshadow the condition of segmentation which occurs later both externally and internally in the segmented worms.

Regeneration

Regeneration is the power to reproduce lost parts out of the body cells, to redevelop the entire organism from a part. The understanding of this function will aid in the understanding of progressive organization, for the power to regenerate has been progressively lost in the animal kingdom, just as specialization has been progressively gained. In Hydra, one twenty-fourth of the animal can regenerate the whole. In man, regeneration is limited to small areas of skin tissue.

Planaria is so easily handled in the laboratory that class experiments are best carried on with this form. The only necessary precaution is to keep the dishes covered to prevent drying. The Planaria can be cut into three or four parts with a sharp knife; each part placed in a separate dish, and watched daily. The parts should be labelled from the head back, *A*, *B*, *C*, and *D*.

A and *B* should give invariably good results. *A* will form a new tail, and *B* a new head and tail. *C* may make a head and tail but it will take longer and the head will be less perfect. *D* is not likely to form any head at all. In fact, if it is cut far enough back it may make two tails.

Planaria can be cut obliquely, longitudinally, or in any conceivable way, and, unless too badly mutilated by the cutting, regeneration will take place, for the normal position of the cells is the position of physiologic balance and the tendency is always to restore that balance. If cut through, or very close to, the eyespots, the balance cannot be so easily restored and the chances are two heads will be formed, one in each direction. If cut directly between the eyes and the cut tissue prevented from healing, a double-headed monster will be formed.

Planarian tissue heals very rapidly and, for this reason, pieces can be grafted on. Whole Hydra have been grafted together also and made to resemble a branching colony. Some have appeared to flourish in that state.

The progressive loss of regeneration is due to the establishment of physiologic gradients. In Hydra, the organism is so generalized, and the formative cells are so well scattered that the whole animal can be crushed and passed through a sieve of fine gauze, and still grow whole organisms from the strained material. But in Planaria the power of regeneration is graded along the anteroposterior axis, just as the energies are.

The secret of the gradients lies in the dominance of one part over another. *B* is able to make a head if *A* is removed, but ordinarily *B* does not make head tissue, because the head exerts an inhibiting influence on the protoplasm behind it. In other words, *A* is the physiologically dominant part.

All florists are familiar with this phenomenon in the dependence of one bud on another. In chrysanthemums the buds grow in clusters about an apical bud. The clipping of the lateral buds allows the apical bud to produce a much larger blossom, for the energies of the plant are divided among them all. Just so, if the apical bud is removed the lateral cluster will attain a larger size.

On page 105 in the discussion on phytohormones, growth inhibiting hormones are shown to be secreted in the apical bud. These prevent the lateral buds from developing.

The only hormones at the present time indicated in invertebrates are those found in the nervous system. The function of these has not been determined, but future research may show that hormones control the inhibiting effect of the head in Planaria, as well as in the apical bud of plants.

In some species of Planaria there are asexual forms which grow at the posterior end, separated from the parent organism by mere constrictions. Child finds that the physiologic gradients make a secondary rise where the head of each new form begins, but that the new zooid will not break off from the parent individual until that organism has become physiologically old, and the dominance of its presence wears out. This gives the new gradients a chance to express themselves, and they are released from the parent organism.

There are two factors, therefore, which determine the success of any part in regenerating tissues: the potentiality of the cell or tissue, and the dominating effect of the metabolic activities of the surrounding cells. Thus, the fate of any cell becomes a function of its position in the organism, not of its inherent potentiality.

But the potentiality of the cells is progressively lost also, and even on removal of the dominant part no regeneration will take place unless the cells retain that power. The anterior end of Planaria makes a double head because the specialization in that region has reached such a high degree that no tissues can be produced from it save those of a similar kind.

A worm can regenerate the whole organism from as little as a third of its structure, a starfish can regenerate whole rays so long as the disc is not injured, and a crab can regenerate its claws; but the insects do not have that power, and in the vertebrates we find that regeneration in the adult is a function of tissues only. A nerve may regenerate a fiber if the cell is not destroyed, and skin can restore small areas, but so small that skin grafts often have to be resorted to, and so imperfectly that scar tissue is frequently formed.

In those organisms which regenerate the whole, the cells which perform this function have retained the whole potentiality of the egg cell, and are only prevented from expressing that power by virtue of the position they occupy. An egg cell is a physiologically undifferentiated and completely balanced cell. In the process of development cells lose this balance by becoming specialized for definite functions, and the balance is only established by the relation of the parts to the whole. In Planaria, the cells, with the exception of those at the extreme head and tail ends, are perfectly balanced, but the energies are graded and there is not sufficient energy in *D* to make possible the expression of the power in the cells.

The most anterior cells are the first to be specialized both in the race and in the individual, for the nervous system is the first to appear in the embryo, and the first to acquire an anterior position. Being the most active physiologically, therefore, they are the first to lose the power of regenerating other tissues. Thus we find synchronous with progressive organization, the progressive loss of regenerative power.

Alternation of Generations

There is an occasional alternation of generations in some species of Planaria by the formation of the asexual zooids at the posterior end, as previously explained, but it is in the parasitic forms that the alternation is most firmly established, and shows the modifications which go with the retrogressive development of parasitism. The liver fluke, *Fasciola hepatica,* represents an intermediate retrogressive type. It has a reduced digestive tract. The tapeworm, *Taenia solium,* is a completely degenerate type with no digestive tract and practically no organs save those of reproduction and a nervous system.

LIVER FLUKE

The outstanding structural differences from the typical flatworm are the presence of suckers, oral and ventral, by which the animal clings to its host; the absence of eyespots; and the reduction of the digestive tract, and of the excretory and nervous systems. The mouth is on the end of the anterior sucker.

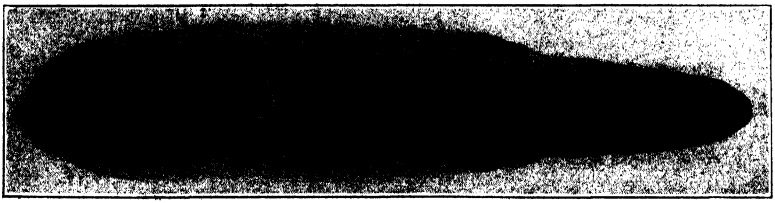

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Fig. 264.—*Clonorchis sinensis.* Oriental human liver fluke, showing male and female reproductive organs. (Photomicrograph by Albert E. Galigher.)

The adult is a parasite in the liver of sheep where the fertilized eggs escape from the uterus of the fluke and enter the bile duct of the sheep to pass thus into the intestines and out

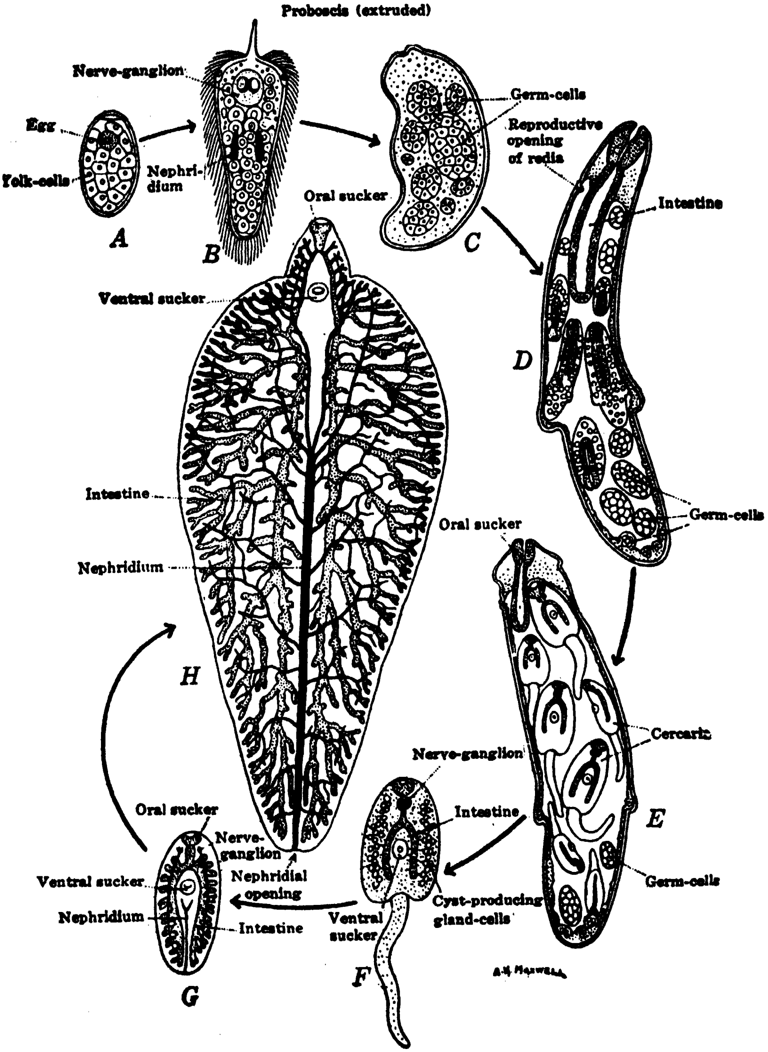

Fig. 265.—Diagrams to illustrate the life cycle of the liver fluke, *Fasciola hepatica*. *A*, Egg; *B*, miracidium; *C*, sporocyst; *D* and *E*, rediae; *F*, cercaria; *G*, encysted stage; *H*, adult (showing digestive and excretory systems only). (Reprinted by permission from Hegner: College Zoology. Published by The Macmillan Co.)

of the animal with the feces. If their environment continues to be moist, they will then develop into ciliated larvae which swim about until they encounter a specific species of fresh water snail, Lymnaea. If the snail is not found within eight hours, these larvae die; therefore, the elimination of the parasite can be accomplished by the elimination of the snail.

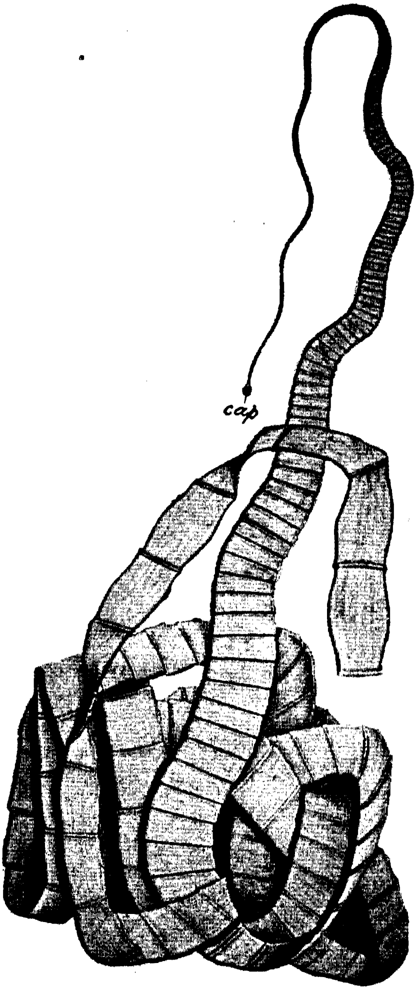

Fig. 266.—*Taenia solium,* ~~entire~~ specimen, reduced. *cap,* Head. (After Leuckart.) (Reprinted by permission from Parker and Haswell: Zoology. Published by The Macmillan Co.)

The larva is known as the *miracidium* and possesses a double eyespot and a pair of excretory organs. If the snail is found, the larva will bore its way in by a twisting motion, and there, by a process of metamorphosis, will develop into a *sporocyst,* a saclike body which has lost the cilia, eyespots, and all the organs of the miracidium, but which produces germ cells in abundance. The power of a larval form to produce germ cells is called *paedogenesis.* The eggs produced require no fertilization but develop by *parthenogenesis.* The form produced is a *redia* which repeats the process of parthenogenetic development, producing more rediae for an unlimited period. This is comparable to the asexual stage of alternation in the Coelenterata but is rather a unisexual than an asexual process, since eggs are formed.

A third larval type is formed in time, the *cercaria,* which differs from the redia only in the possession of a tail, which enables it to swim. It leaves the snail, therefore, and swims about on the moist grass. It will encyst itself on some blade of grass or leaf until chance sends the sheep that way. If eaten, the cercaria will escape from the cyst, swim to the bile duct, and, by a further metamorphosis, develop into an adult fluke. This is the sexual form. The fluke is hermaphroditic, as is Planaria.

A considerable amount of chance operates in the completion of this life cycle, and the complexity of the process has probably been evolved in order to minimize the danger in transferring from one host to the other.

TAPEWORM

The tapeworm is an extreme type of parasitic degeneration. There are many species, some infecting dogs, horses, cats, rats, and even birds, and each species has its own secondary host. The species described, *Taenia solium,* is a common parasite in the intestine of man. Its secondary host is the pig, which it infects by invading the muscles, so that eating of underdone pork is the only means of contracting the parasite. There are other species which attack man, however, *Taenia saginata* being acquired from the muscles of beef and *Bothriocephalus latus* from the muscles of trout, and other fresh water fish.

The body of *Taenia solium* consists of a scolex with a short neck and a linear series of proglottids formed by budding from the neck tissue, the most recently formed proglottid being adjacent to the neck. The animal attaches itself to the wall of the human intestine by means of four suckers and a ring of hooks and continues to bud proglottids until the length is sometimes greater than the intestine it inhabits. It takes its food predigested by absorption through the body wall, thus robbing the host, and often causing great emaciation in spite of an enormous appetite.

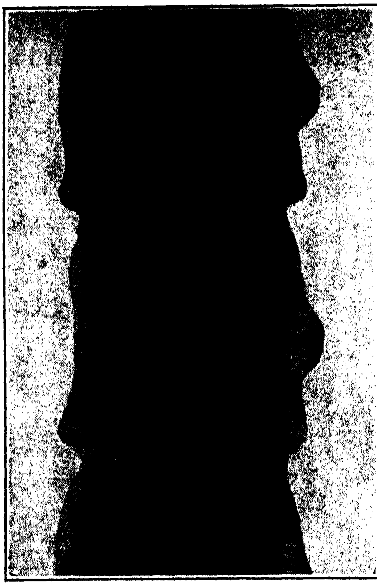

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Fig. 267.—*Taenia serrata.* Mature proglottids of tapeworm from a dog, showing male and female reproductive organs. The genital openings are shown at the right. The secondary host of this species may be a rabbit or a mouse. (Photomicrograph by Albert E. Galigher.)

Since the food is predigested, there are no digestive organs. Lateral nerves and excretory ducts run through the length of the animal, but otherwise there is little organization. Each proglottid is a separate sexual individual with a complete set of male and female organs. The proglottids mature at the terminal end first. As each matures it drops off and escapes from the host in the feces. The eggs develop into *six-hooked embryos* while still within the proglottid, and if eaten by a pig they escape from their surrounding envelopes and bore their way through the digestive tract to the muscles where they form *cysts,* or bladder worms. Inside the cyst the scolex of the adult is formed. It is then called a *cysticercus.* It is in this form that it remains until eaten by man in the pork muscle. If eaten, the scolex is everted and attached to the wall of the intestine.

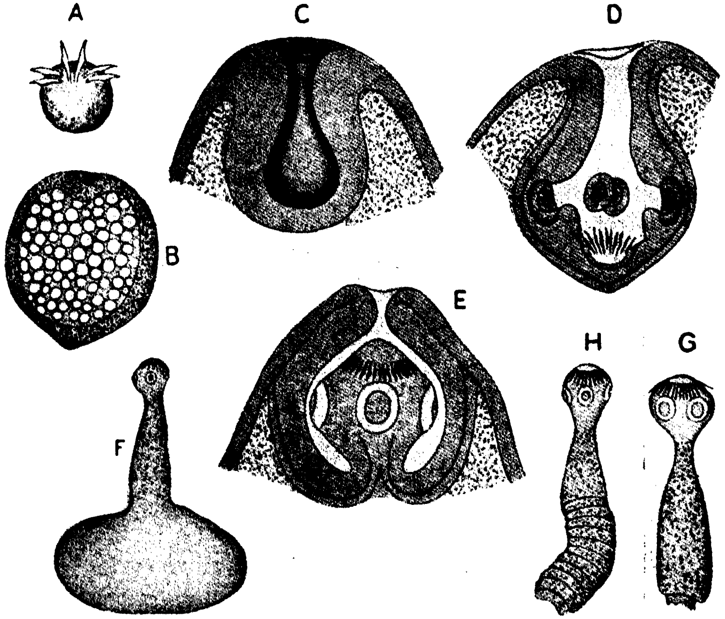

Fig. 268.—Development of a tapeworm. The six-hooked embryo (A) becomes attached to the muscle of the pig, and develops into cysts, or bladder worms (B), in which the scolex of the adult is formed. (After Leuckart.) (Reprinted by permission from Parker and Haswell: Zoology. Published by The Macmillan Co.)

This is not a true case of alternation of generations, for the proglottids lead no separate existence and are really a part of the adult body. It is often spoken of as *pseudo-alternation* since it does accomplish the transfer from the primary to the secondary host.

ROUND TYPE

Roundworms

The roundworms form a more highly organized group of bilateral animals than the flatworms. They have three germ layers; anteroposterior, ventrodorsal, and bilateral axes, and, in addition, an anus and a body cavity. They are entirely unsegmented, internally and externally, and are, therefore, not a further progression of the flatworm type, but an independent development from the coelenterate group. On this distinction between the segmented and the unsegmented series rests the branching of the animal kingdom into two main lines called, respectively, the teloblast series and the enterocoele series. This division is further based on embryologic development as explained on page 582.

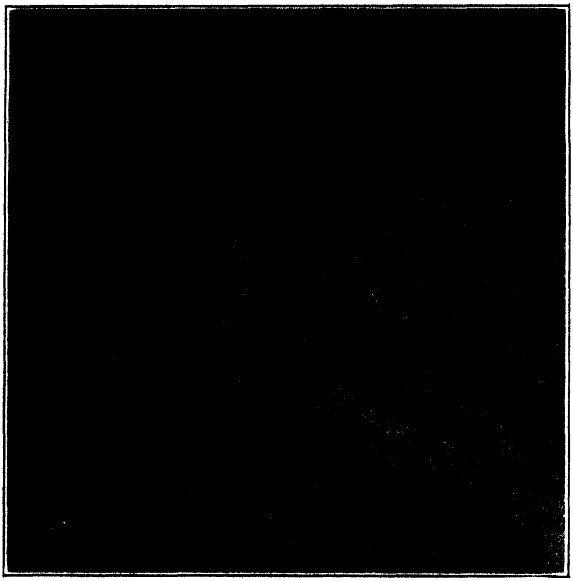

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Fig. 269.—*Trichinella spiralis,* a parasitic roundworm of the enterocoele series, photographed in a piece of infected pork muscle. The roundworms are unsegmented, coelomate forms. (Photomicrograph by Albert E. Galigher.)

Roundworms are characteristically minute, although a few species reach a length of several feet. The muscular contortions of the elongate, cylindrical body produce a whiplike lashing motion by which they are easily recognized. They are mainly parasitic, although a few free-living nematodes are among the common species. They are so universal that every conceivable type of moist environment contains them. Running water and still water, salt water and fresh water, moist

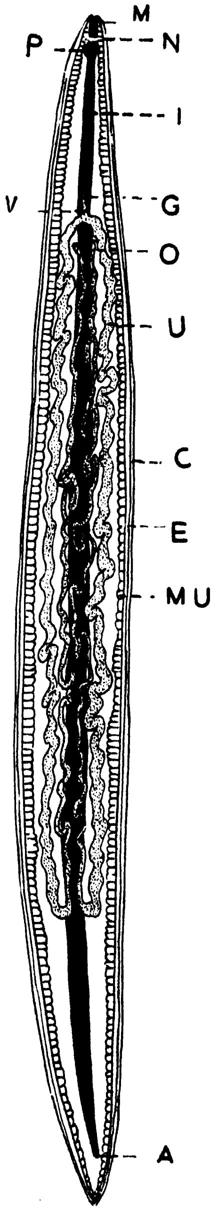

Fig. 270.—Ascaris, internal view. *M*, Mouth; *N*, nerve ring; *P*, pharynx; *I*, intestine; *G*, genital pore; *V*, vagina; *O*, ovary; *U*, uterus; *C*, cuticle; *E*, epidermal layer; *MU*, muscle layer; *A*, anus.

sand and mud, and even moist vegetation and fruit juices provide their habitats. So numerous are they, that it is said that any moist top-soil of arable land may produce thousands of millions of individuals to an acre.

As parasites, they are irritating and debilitating to their hosts, but only in rare cases are they fatal.

Ascaris lumbricoides.—Ascaris is a common intestinal parasite, the species *lumbricoides* infecting man. The living worm has a shiny white appearance from the chitinous cuticle which has four white stripes running the length of the body, narrow dorsal and ventral ones, and broader lateral ones.

Anatomy.—Being a parasite, only a very simple digestive tract is required, all food being predigested. The mouth at the anterior end is circled by one dorsal and two ventral finely toothed lips. It opens into a small buccal vestibule from which extend a muscular esophagus and a long nonmuscular intestine. The intestine narrows posteriorly into a rectum which opens through the anus in the female, but into a reservoir, called the *cloaca*, in the male. The cloaca also receives the genital ducts and, in turn, opens through the anus.

The digestive tract lies in a cavity, but neither structurally nor functionally is this cavity a true coelom, for a coelom should be a slit in mesoderm cells, and there is no mesoderm surrounding the intestine. Moreover, the mesoderm lining the body wall does not give rise to the reproductive cells, as is the rule in higher forms. Nevertheless, this is the first appearance of a body cavity in the tissue animals, and it is thus of significance.

The body wall is surrounded by a thin cuticle of chitin, under which is an epithelium, one layer of cells thick. Beneath this is a thick layer of tissue containing longitudinal muscle fibers. Laterally, there are two lines in which are embedded two long excretory canals which open to the outside by a single pore, near the anterior end of the ventral body wall.

A ring of nervous tissue surrounds the esophagus, and from it, dorsally and ventrally, run two long unganglionated cords.

Reproduction.—There is a sharp sexual dimorphism in Ascaris. The males are much more minute than the females, which may attain a length of five to eleven inches. The posterior end of the male bends forward, and two *penial setae* extend through the anus. These are placed in the genital opening of the female during copulation. The anus is further surrounded by numerous papillae. Internally, a single coiled testis leads into a narrow vas deferens. This widens into a seminal vesicle, which leads to an ejaculatory duct. The duct opens into the cloaca and serves to force the sperm into the female during copulation.

In the female fertilization takes place in the uteri of which there are two, joining to form a short vagina. The genital opening, called the *vulva,* is a transverse slit a little forward of the middle.

Life History.—The mode of life of Ascaris is characteristic of many of the parasitic nematodes. Embryos or developing eggs abound in the soil in communities where sanitation is not practiced. They live in the soil for months, and transfer is made by dirty hands from the soil to the mouth. Thus the disease is most common in children.

The eggs hatch in the intestine and mature there, but do not spend their entire time there. The larvae bore through the intestinal walls and make a tour of the body before settling down to mature. When they leave the intestine, the larvae have the choice of two paths following the digested foods. They may pass into the liver through the portal vein and thence to the heart and lungs; from the lungs they return to the intestine by way of the trachea. The other path is similar except that it avoids the liver, passing to the heart through the thoracic duct.

If large numbers of parasites are present, the lungs may become inflamed and pneumonia may result. In the intestines, obstruction may occur and nervous symptoms are frequent. Oil of chenopodium is used to remove the parasites from the intestines.

CHAPTER XXVI

METAMERIC ORGANIZATION

ANNULATA

A further development of the bilateral type is found in the Annulata, commonly called the annelids. This phylum includes the elongate segmented worms, which are typically marine, and possess a pair of swimming appendages on each segment. Their structure marks a decided advance over the flatworms.

Organization

1. The digestive tract is complete, with an anterior mouth and a posterior anus.
2. A coelom, the true body cavity, has appeared as a cavity in the mesoderm, lined by epithelial cells.
3. The body is divided into a series of segments, called metameres or somites.
4. Cephalization has advanced.

Both the coelom and the segmentation are new developments, and are of fundamental importance, since they are typical of the organization of the most highly organized animals, the arthropods and the vertebrates.

In the annelids metamerism is more perfect than in any other group. Each external ring is continuous with an internal partition, the *septum,* which passes through the coelom and is attached internally to the outer wall of the digestive tract. The internal organs are typically repeated in every segment.

Although this is the first appearance of metamerism, the condition was foreshadowed in the flatworms by the serial repetition of the internal organs.

If it be true that this internal repetition of organs is the primitive metamerism, then the group called the archiannelids is a primitive group within the annelids; for segmentation is complete internally but is only faintly marked externally.

In the earthworm, segmentation is complete inside and outside as in the typical worms, but only a part of the organs is serially repeated, the reproductive organs being limited to certain of the anterior somites.

The swimming appendages are lacking, and the *trochophore* larva, typical of the marine annelids, is lacking also. A typical marine worm is *Nereis,* the clam worm. It has all the typical annelid features, including the trochophore larva which is the larval type characteristic of the metameric series of animals. For practical purposes the earthworm is chosen as an illustration of metameric organization, since it can be obtained alive on any college campus at almost any season of the year.

EARTHWORM

The earthworm, *Lumbricus terrestris,* lives a semi-terrestrial life, and its structure is modified for the creeping and burrowing habit. The swimming appendages of the marine worm would be of little use under ground, and only a few bristles remain of the marine appendage. These are called *setae.* They are useful in pushing against the sides of the burrow, and so aid in moving the worm along.

Although modified for a terrestrial life, the earthworm is not air breathing, for it breathes by absorbing oxygen from the moist subsoil, and cannot withstand drying. The numbers left stranded on the walks after a rain testify to this. Ordinarily they do not leave their burrows except at night, when they forage about the vicinity of the burrow with the posterior end anchored to the entrance, preparatory for immediate retreat. Their hydrotropism is so strong, however, that they cannot resist the extreme moisture brought on by the rain, even though they are negatively tropic to light.

External Structure

There are over a hundred somites, and it is customary to represent them by Roman numerals. A thin

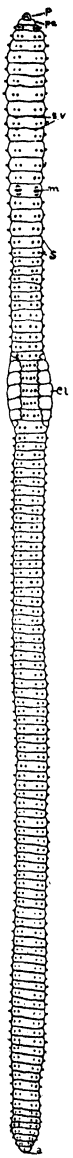

Fig. 271.—The earthworm. Ventral surface. *P,* Prostomium; *pe,* peristomium; *sv,* openings of the seminal vesicles; *m,* opening of the male pore; *s,* setae; *cl,* clitellum; *a,* anus. (Drawn from the specimen by Harriet Philips.)

cuticle covers the entire body, and is pierced by holes through which secretions of the glands and excretions from the body gain egress. The cuticle is finely striated, and the striations reflecting rays of light cause the iridescence which is often seen on the surface.

The *prostomium*, which extends like an upper lip over the mouth, is not a true segment, but is anterior to somite I. The ventral mouth is crescentic in shape and is on the first somite; the oval *anus* is at the terminus of the last segment.

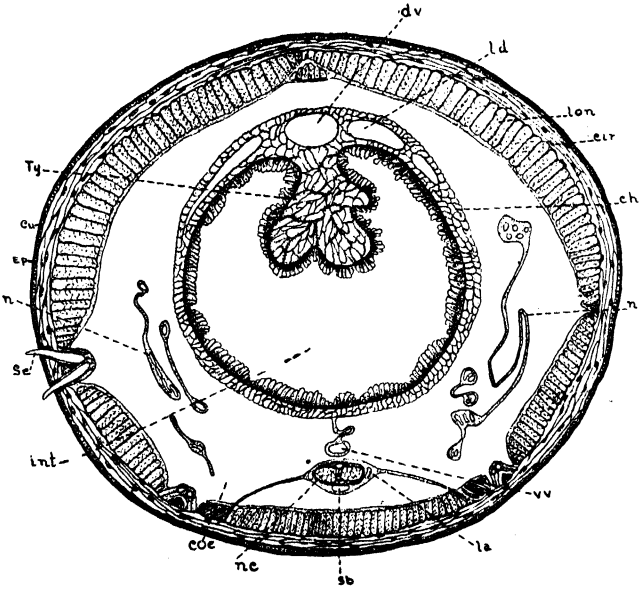

Fig. 272.—The earthworm. Cross-section through a posterior somite. *dv*, Dorsal blood vessel; *ld*, lateral branch of blood vessel; *lon*, longitudinal muscle fibers; *cir*, circular muscle fibers; *ch*, chloragogue cells; *n*, nephridium; *vv*, ventral blood vessel; *la*, lateral neural vessel; *sb*, subneural vessel; *nc*, nerve cord; *coe* coelom; *int*, intestine; *se*, seta; *ep*, epidermis; *cu*, cuticle; *ty*, typhlosole. (Original drawing by Elizabeth Drumtra.)

From somites XXXI to XXXVII in mature worms there is a swollen area, the *clitellum*, which functions in reproduction. Sensory hairs are found at the anterior end, and, to a lesser extent at the posterior end. There is a complete absence of sense organs.

Every segment except the first and last has four pairs of *setae*, the chitinous bristles which are moved by muscles in the body wall. These represent the bristles on the typical flaplike *parapodium* of the marine worms.

With these few exceptions, the earthworm is devoid of external organs, the only remaining structures being the external openings of the internal organs, which are many since there is no communication between somites and each must have its external ducts. On the ventral surface between somites IX and X, and X and XI, are two pairs of minute pores, the openings of the *seminal receptacles*. The female genital openings are on somite XIV, and the male on somite XV, the earthworm being hermaphroditic. On the ventral surface of each segment except the first three and the last are two excretory pores, and on the middorsal line of every segment back of the ninth is a dorsal pore.

Internal Structure

Except for the first two, septa separate the body cavities of each somite, so that the body, on dissection, has the appearance of a series of tubes. The coelom in each is filled with a colorless fluid, the lymph, in which white blood corpuscles are present. The red blood is enclosed in vessels.

Organs of Digestion.—*The buccal cavity* into which the mouth opens occupies somites I to III; the muscular *pharynx,* somites IV and V. The narrow *esophagus* extends from somite VI to XIV, widening into a thin-walled *crop* in somites XV and XVI, which is separated by a constriction from the thick-walled *gizzard* in somites XVII and XVIII. The tube then narrows into a long *intestine* which serves also as a stomach and extends to the last three segments where there is a section without any glands which serves as a *rectum,* and opens through the *anus.* The dorsal wall of the intestine folds in to form the *typhlosole* which increases the surface for digestion and absorption. A layer of brownish *chloragogue cells* surrounds the intestine and three pairs of *calciferous glands* will be found on each side of the esophagus in somites X to XII.

Organs of Circulation.—There are two fluids in the body: the colorless lymph in the coelom, and the red blood in the closed vessels. The *hemoglobin* which carries the oxygen is dissolved in the plasma instead of being carried by the corpuscles, as in the vertebrates. The corpuscles so called, are colorless cells and are found in both the lymph and the blood.

The lymph passes from one somite to the other by osmosis through the septa; the red blood is propelled by contractions of the *dorsal* blood vessel and the five pairs of *hearts* which extend around the esophagus in somites VII to XI, connecting the dorsal vessel with the *ventral* vessel. There are three other longitudinal trunks; the two *lateral neural* and a single *subneural* in the midline, the latter being connected with the dorsal vessel by means of small *parietal* vessels. There are many capillaries in the end organs making this an efficient means of carrying oxygen, digested foods, and waste materials from one organ and one somite to another. There are valves in the dorsal and ventral vessels which prevent the backflow of blood.

Organs of Respiration.—There is no organized system for respiration, this function being the last to acquire specialization in the aquatic animals. The earthworm breathes through the moist outer membrane by *osmosis,* for which reason moisture is essential in its surroundings. The exchange of gases takes place in the capillaries of the closed system.

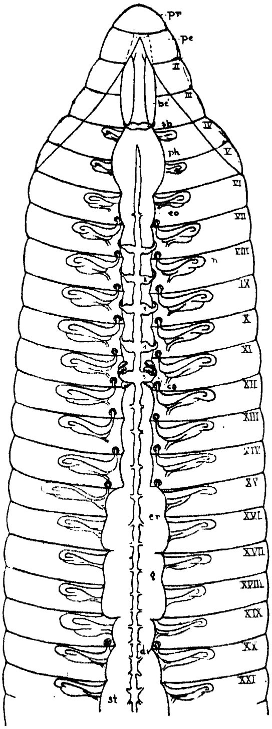

Fig. 273.—The earthworm. Semidiagrammatic view of a dorsal dissection. *pr,* Prostomium; *pe,* peristomium; II-XXI, somites; *bc,* buccal cavity; *sb,* subpharyngeal ganglion; *ph,* pharynx; *eo,* esophagus; 1-5, aortic hearts; *n,* nephridium; *cg,* calciferous glands; *cr,* crop; *g,* gizzard; *dv,* dorsal blood vessel; *st,* stomach-intestine. (Drawing by Harriet Philips.)

Organs of Excretion.—The *nephridia* are a type of excretory organs found in modified form in many other groups. It is the only excretory organ in the invertebrates which has been repeated in more than one phylum, and is probably the most efficient type evolved.

These organs consist of five parts: a ciliated, open *funnel* on the floor of the septum, through which the narrow, ciliated *neck* passes to the *coiled tube* in the next posterior somite. The coiled portion is surrounded by a network of capillaries and is succeeded by a wider *glandular* portion and an *ejaculatory duct*. This latter opens to the outside by a *nephridiopore*. There is a pair of these organs in each somite except the first three and the last.

Organs of Reproduction.—The earthworm is an hermaphrodite and all the sex organs are concentrated in the anterior end.

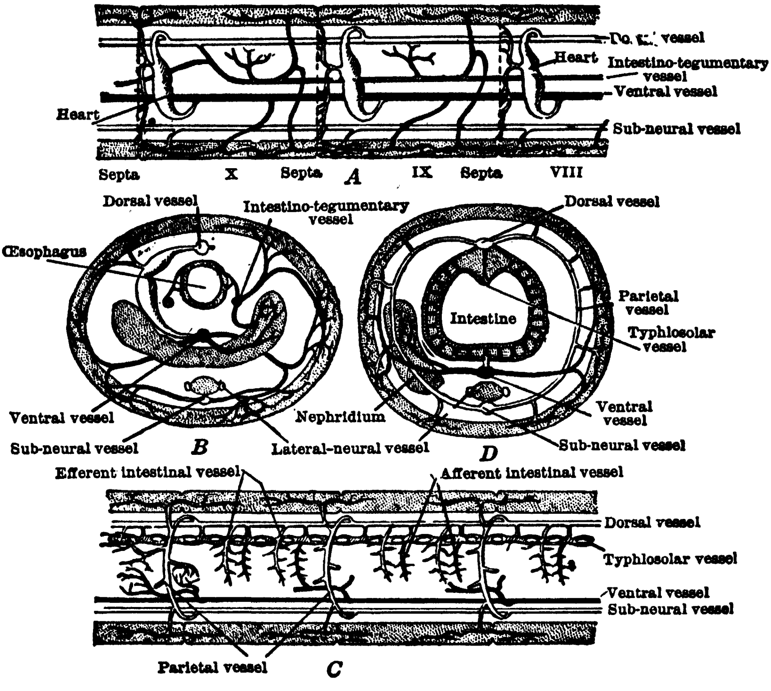

Fig. 274.—Diagrams showing the arrangement of blood vessels in the earthworm. *A*, Longitudinal view of the vessels in somites VIII, IX, and X. *B*, Transverse section of same region. *C*, Longitudinal view of the vessels of the intestinal region. *D*, Transverse section through same region. (From Bourne, after Benham.) (Reprinted by permission from Hegner: College Zoology. Published by The Macmillan Co.)

The female organs: One pair of *ovaries* hangs from the anterior septum of somite XIII; one pair of *oviducts*, with their open funnels on the posterior septum of the same somite, passes through the septum, enlarges into *egg sacs* in somite XIV, and opens to the outside in the same segment. Two pairs of *seminal receptacles* for receiving sperm are in somites IX and X, with their openings in the grooves between the somites.

The male organs: Two pairs of *testes* in somites X and XI are attached to the ventral wall. The Y-shaped sperm duct, or *vasa deferentia*, extends from each of these somites to unite in somite XII into the single duct which opens to the outside in somite XV. There are three pairs of large seminal vesicles in somites IX, XI, and XII.

Organs of Conduction.—The nervous system of the earthworm is well developed, a large bilobed dorsal ganglion in somite II serving as a *brain.*

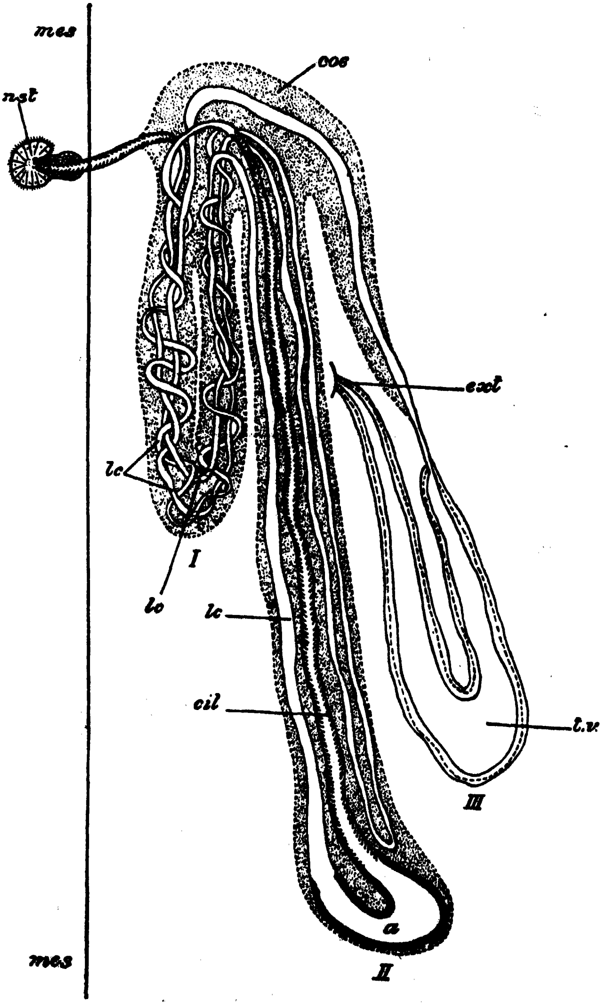

Fig. 275.—Earthworm. Diagram of a nephridium. *A*, Ampulla between the ciliated and nonciliated parts of the intracellular canal; *cil*, ciliated canal; *coe*, part derived from the coelomic epithelium; *ext*, external opening; *lc*, nonciliated canal; *mes*, septum between somites; *nst*, nephrostome; *t.v.*, intercellular canal; I-III, the three principal loops. (From Meisenheimer, after Mazlarski.) (Reprinted by permission from Hegner: College Zoology. Published by The Macmillan Co.)

Since this ganglion lies dorsal to the pharynx, it is called the *suprapharyngeal ganglion,* and is connected by the *circumpharyngeal commissures* to a *subpharyngeal ganglion* on the ventral side. A double ventral nerve cord extends from this point to the posterior end of the body. In each segment is a bilobed enlargement and three pairs of peripheral nerves.

Organs of Sensation.—There are no sense organs but the entire epithelium is sensitive. *Sensory hairs* are concentrated at the anterior end with a few at the posterior end. For the rest, *sensory cells* in the epithelium suffice.

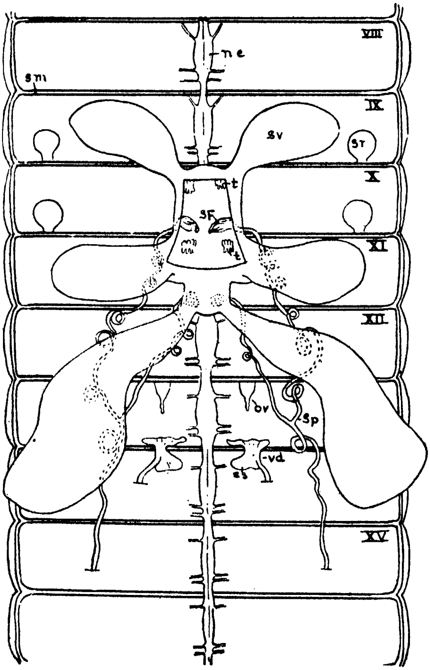

Fig. 276.—Earthworm. Semidiagrammatic drawing of somites VIII to XV, showing the reproductive organs and the nerve cords. The seminal vesicles have been cut away in somites X and XI to disclose the testes and sperm funnels. *nc,* Nerve cord; *sm,* septum between two somites; *sr,* seminal receptacle; *sv,* seminal vesicle; *t,* testis; *sf,* seminal funnel; *sp,* sperm duct (vas deferens) opening in the fifteenth somite; *ov,* ovary; *vd,* oviduct; *es,* egg sac. (Drawing by Harriet Philips.)

The Reflex Arc.—For the first time in the animal kingdom, definite reflex arcs can be traced, connecting the sensory cells of the epithelium with the dermal musculature. A reflex arc implies a *sensory cell* to receive the stimulus; an afferent fiber to conduct the stimulus to the central nervous system; transfer of the stimulus to a *motor nerve cell;* and conduction of the stimulus by *an efferent fiber* which ends in a muscle.

A *neuron* is a nerve cell which consists of a cell with an *axone* to transmit the stimulus, and *dendrites* to receive it. The axones of a sensory cell transmit the stimulus to the dendrites of a motor cell. The two nerve fibers in no case come in contact but pass the stimulus across. No neurohormones have yet been identified in the earthworm but may be the means of transmitting the stimulus across.

There is such an arc complete in every somite of the earthworm, with accessory neurons which carry the stimulus from one somite to another, so as to coordinate the action of all.

Organs of Locomotion.—Locomotion is largely accomplished by contraction of the dermal musculature which consists of an outer layer of circular muscles, and an inner layer of longitudinal muscles. Contraction of the outer layer lengthens the worm by making him narrower; while contraction of the inner layer makes him shorter and thicker. Contraction usually passes as a peristaltic wave along the body, and burrowing is accomplished by contracting the two layers alternately.

In addition to the muscles, the four pairs of *setae* in each segment act as accessory organs of locomotion by pushing against a rough surface.

Behavior

The earthworm has been the object of more detailed observation than almost any other species. Charles Darwin spent forty years studying its habits, and the results are gathered into his book, *The Formation of Vegetable Mold Through the Action of Worms.* One cannot read the carefully gathered data without a keener appreciation of the economic value of the lowly worm, and the perfect adaptation of its mechanism to the creeping, crawling, burrowing type of life. All the modifications of the earthworm which vary from the standard of the marine types are adaptations to this mode of life.

By contractions of its dermal musculature, the worm burrows its way through the earth, eating the dirt and small stones as it goes. The burrows run through the earth about five or six feet from the surface in dry seasons. They are lined with dead leaves from which the mesophyll cells have been sucked out for food. The worm remains in the burrow during the day breathing by means of diffusion from the moisture surrounding it. By night it emerges with its tail attached to the burrow, and by exploring movements in the radius of its length about the burrow, selects small bits of animal and vegetable food which it swallows along with the dirt.

When attached to the burrow, retraction is sudden and swift, but if swept from its anchor by a rainstorm, or lured out by the darkness and moisture of a rainy day, it may be unable to locate the entrance to the burrow. If not dried in the meantime, it may start a new one, but the membrane does not retain moisture for any length of time in the presence of air.

Any stimulus of light, touch, vibrations, or chemicals other than food, will cause retraction, but chemicals must be in solution and must touch the body wall. It is apparently devoid of any sense akin to smell. Its reactions are all negative except to water, to which it responds positively if it comes in contact. The sensitive hairs of the anterior and posterior ends account for the fact that both ends are sensitive to light, while the central region is not. They are negatively phototropic.

The protective qualities are largely in its strong musculature which enables it to retract swiftly, and to contract the body so as to slip out of the grasp when held. Attempts to pull a worm out of its burrow will be unsuccessful unless a firm but gentle pressure is used. If jerked up, it will break off, leaving one-half of the worm in the hole. This is to its advantage since the piece remaining can regenerate the whole.

The cuticle is also protective, being impervious to harmful substances in solution, and the mucous secretion makes it slippery to the touch.

Summary of the Physical Function

Sensation: Sensory cells in epithelium; sensory hairs at anterior and posterior ends.

Conduction: Dorsal and ventral bilobed ganglia with connecting commissures; a double ventral nerve cord with ganglia in each segment; peripheral nerves.

Locomotion: Circular and longitudinal muscles; setae.

Protection: Cuticle; mucous secretion.

Nutrition

The food of the earthworm consists of the minute particles of animal and vegetable matter which it sucks through its mouth by the action of the pharyngeal muscles. In this way leaves are skeletonized, all the mesophyll cells being sucked into the mouth; the remaining portion of the leaves is used to line the burrows. This combination of dirt and food passes slowly through the digestive tract, moistened by the secretions from the cells lining the digestive tract, and made alkaline for tryptic digestion by the calcium carbonate secreted from the calciferous glands. The crop acts as a reservoir, holding the food in abeyance until the gizzard has ground the material in advance. This grinding is a very important function in the earthworm, since by it the dirt eaten is reduced to very fine particles and is mixed with secretions which make it a rich fertilizer when returned to the soil.

The digestive juices are secreted from the wall of the intestine, the surface of which is increased by the dorsal fold, or typhlosole. As the ground material passes through the intestine, the nutritive part is digested and absorbed, the dirt is passed on to the anus, and is egested with the aid of the short rectum. The feces, or castings, are deposited as little heaps of earth on the surface of the ground. By this means, the material of the subsoil is brought to the surface and in the course of time, the entire soil will be redistributed. Darwin estimated that more than eighteen tons of castings may be thus transferred to the surface in a single acre in one year, and in the course of a few years the stony surface may be completely buried by the activities of the busy worm. Fortunate it is for the farmer that the worms he severs with his plow regenerate two perfect worms.

The digested foods are absorbed through the intestinal wall by diffusion, assisted by the activity of amoeboid cells. Capillaries of the blood stream take it and carry it into the lateral neural and subneural vessels in which the movement is posterior. From these vessels it is transferred to the dorsal vessel by means of the parietal vessels and is carried forward by the active pulsations of the dorsal vessel. The pulsations are still felt in the five hearts which carry the blood to the ventral vessel, and thence as it moves posteriorly, the blood is passed into capillaries which carry it to the cells where the digested food and the oxygen can be removed and carbon dioxide and nitrogenous wastes received, to be removed by the secretory portion of the coiled nephridial tube.

Respiration is carried on by diffusion, but excretion is accomplished by the nephridia, although the dorsal pores excrete some waste products also. The funnel of the nephridium creates a powerful current by means of the strong cilia in the narrow opening. If carmine be injected into the body cavity, it is taken up by the chloragogue cells and then released together with the broken down cells into the lymph, whence it is caught by the ciliary currents and carried to the funnel of the nephrostome. Therefore, the chloragogue cells must be considered excretory in function. The materials thus excreted are probably salts and other substances in solution in the lymph.

The nitrogenous wastes of the body are brought by the blood stream to the capillaries which are in close contact with the coiled portion of the tubes. The function of the nephridia, therefore, is twofold, serving to rid the body of wastes and of excess water. Excretion is by the ejaculatory duct.

SUMMARY OF THE CHEMICAL FUNCTIONS

Digestion: Mouth, pharynx, esophagus, crop, gizzard, intestine, calciferous glands, tryptic enzymes.

Absorption: Diffusion assisted by amoeboid cells.

Circulation: Closed system with dorsal blood vessel and five pairs of aortic arches acting as hearts. Also lymph in coelom.

Respiration: Diffusion through cuticle in direct contact with capillaries.

Excretion: Nephridia, one pair in each segment; chloragogue cells.

Reproduction

The copulatory habits of the earthworm are of interest as illustrating cross-fertilization in an hermaphroditic form. In the spring the clitellum in mature worms becomes swollen and enlarged. The worms overlap one another in such a way as to bring the ventral surfaces of the ninth and tenth somites of each in close proximity to the fifteenth somite of the other worm. A thick mucous secretion forms in the region of the clitellum which envelops both worms and holds them together while the sperm are passed from the sperm ducts of each individual through the openings in the fifteenth segment into the seminal receptacles of the ninth and tenth somites of the other individual.

This completes the process of copulation, after which the worms separate. The mucus from the clitellum forms a slime tube which is now loosened from the body and slips forward toward the anterior end, gathering albumen from the glands on the ventral surface. As it passes the fourteenth somite, eggs from the oviducts pass into the tube, and as it passes the ninth and tenth somites, the seminal receptacles empty their contents into it. The tube then slides forward over the head of the worm, the anterior end closing tightly as it passes the head as though drawn with a string. This closed tube is a

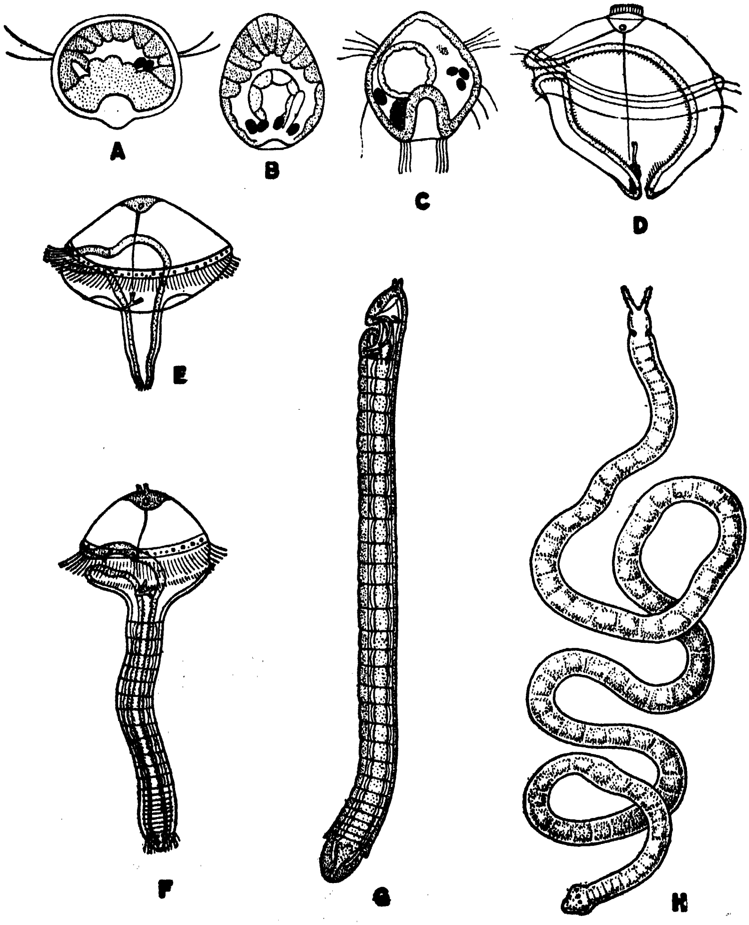

Fig. 277.—The development of Polygordius, an archiannelid. *A,* Blastula; *B,* gastrula; *C,* early trochophore larva; *D,* optical section of trochophore larva showing apical plate with eyespot, head kidney, and preoral band of cilia. *E,* Trochophore larva with posterior growth region; *F,* segmenting larva; *G,* advanced larval condition in which the trochophore larva is seen to be the head, with mouth, eyespots, and tentacles; *H,* adult worm, showing faint external segmentation. (Drawn from an unpublished chart by Whitman.) (Reprinted by permission from Newman: Text Book of General Zoology. Published by The Macmillan Co.)

cocoon in which the fertilized eggs develop into a young worm without metamorphosis. The development is greatly modified from the usual annelid type.

AFFINITIES OF THE ANNELIDS

To establish the relationships of the annelid group, two things must be taken into consideration: (1) the development of the mesoderm tissue in the embryo, and (2) the development of segmentation.

Origin of the Mesoderm

The invertebrate animals have shown two definite trends in development, each characterized by specific methods of deriving the third germ layer, the *mesoderm,* from the two-layered embryonic gastrula (see page 260). The annelids belong to the *teloblast series* in which the mesoderm develops from two *teloblast cells* which appear at the anal end of the *trochophore* larva just before segmentation starts (Fig. 277, *E*).

The trochophore is a small, free-swimming larval form which is not much more than an animated gastrula stage of development. The name comes from the Greek, *trochos,* a wheel, and *phoros,* a bearer, and refers to the circlet of cilia by means of which it moves rapidly in the water.

The main part of the trochophore will become the head of the adult, the body elongating from the posterior end. The larval anus is the embryonic *blastopore,* and it is on either side of this opening that the teloblast cells appear. These cells proliferate in a posterior direction to mark off the somites. Within each somite the cells proliferate in all directions to completely fill the somite with mesoderm cells. Later a split occurs in the mass of cells and the cavity in each somite is a true coelom. The cells further differentiate to form the organs. Only after the somites have been marked off internally do the external indentations appear. In Polygordius, Fig. 277, *H,* the segmentation is only faintly marked externally.

This development is so characteristic of the trochophore larva that all groups in which the trochophore, or any modification of the trochophore, is the usual larval form are believed to have had a common origin and are assigned to the teloblast series whether segmented in the adult stage or not.

In fact, so enthusiastic about the trochophore are some biologists that they believe the ancestral annelids to have been short and unsegmented, somewhat resembling trochophores. Such a group exists in the Trochelminthes, which include the rotifers, commonly spoken of as *wheel animalcules* because of the rings of cilia which resemble spinning wheels when in motion. The rotifers probably are adults which have retained the trochophore stage of development and represent only the head of the annelids. As the early primitive groups seen in the flat worms tended toward elongation and the repetition of internal organs, the trochophore view of annelid development appears untenable.

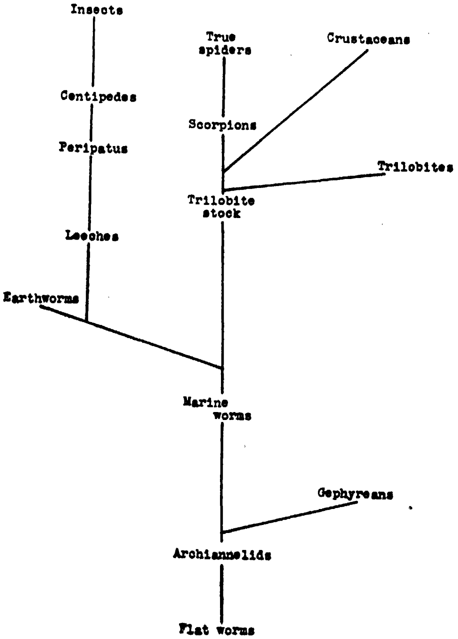

Fig. 278.—Diagram to illustrate the affinities of the Annelids.

Development of Segmentation

On the assumption that segmentation originated internally by the serial repetition of organs, Polygordius is a primitive annelid. Proponents of the trochophore theory consider this a derived condition. A series is here outlined to show how segmentation, after cutting through to the outside, gradually broke down internally, leaving the strongly marked external segmentation in the exoskeleton of the arthropods. The series outlined leads to the air-breathing arthropods. The marine Crustacea and the Arachnida are believed to have had a similar origin from the marine worms through the trilobites of prehistoric days. Since the internal structure of the trilobites is shrouded in antiquity, no series can be determined.

1. *Platyhelminthes.* Type *Planaria.* Internal organs serially repeated in a solid parenchyma; no coelom.

2. *Archiannelida.* Type *Polygordius.* Segmentation complete internally, only faintly marked externally.

3. *Chaetopoda*—typical annelids. Segmentation complete internally and externally.

    a. *Polychaeta* (marine worms).

        (1) *Errantia.* Free-swimming. Type *Nereis.* Biramous swimming appendages on each segment.

        (2) *Sedentaria.* Burrowing or in tubes. Type *Chaetopterus.*

    b. *Oligochaeta*—modified for terestrial life. Appendages reduced to bristles. Type *Lumbricus.* Believed to be derived from the Errantia by a series of losses.

4. *Hirudinea*—leeches. Type *Hirudo.* A specialized group believed to be still further reduced than the oligochaetes, and possibly derived from them. The internal segmentation has partially broken down, so that several external rings correspond to a single internal somite.

The coelom is a hemocoele, a condition possibly derived from the dorsal blood vessel by the breaking of the walls of the lateral vessels and the extension of their walls to line the cavity.

5. *Onychophora,* an arthropod group. Type *Peripatus.* Although classified as an arthropod, Peripatus shares certain characteristics with the leech type of annelid, and so furnishes a clear transition to the air-breathing arthropods.

    a. Annelid characters. The external rings resemble those of the leech, and the only external secretion is a thin layer of cuticle.

The paired nephridia are of the annelid type, and the systems of organs are arranged as the annelids.

b. Arthropod characters. The paired appendages are specialized on the head into a pair of antennae and one pair of jaws. The body appendages have a pair of claws at the terminal end, but all the appendages are unjointed so are not typical arthropod appendages.

The coelom is a hemocele and is more extensive than in the leeches.

Tracheal tubes adjust it to air breathing, but the arrangement of the apertures is not typical. The salivary glands are the most characteristic arthropod organs.

c. Atypical characters. The arrangement of the tracheal apertures, the single pair of jaws, the lack of joints in the appendages, and the texture of the skin are all characters found in neither annelids nor arthropods. Nor are their viviparous habits typical. One female may produce thirty or more young in a season, and these resemble the adult when born, so have no metamorphosis.

Peripatus is one of several species found in such widely separated habitats as tropical America, Australia, and Tibet. They are active only at night, for they live in dark, moist places. They are quite rare and difficult to locate since they are usually concealed under bark or stones, or in crevices in rocks.

6. *Chilopoda,* the centipedes. Type *Scolopendra.* Centipedes are one group of myriapods and are true air-breathing arthropods in all respects. The internal segmentation is completely lost, the external segmentation is plainly marked, and there is some chitin in the exoskeleton.

The coelom is a hemocoele, the structure and arrangement of the tracheal tubes are like that of insects, and the salivary glands are typical.

7. *Insecta.* Type *Rhomaelia.* The insects terminate the series and are considered the most successful of all the invertebrate groups. The cephalization has progressed; the body segments have been specialized into head, thorax, and abdomen with a corresponding specialization in the appendages. In the insects these are found on the head and thorax only. Those

PROGRESSIVE ORGANIZATION

PHYLUM	SYMMETRY	GERM LAYERS	COELOM	SEGMENTATION	ANUS	CEPHALIZATION
Protozoa	spherical or absent	absent	absent	absent	absent	absent
Coelenterata	radial	two	absent	absent	absent	absent
Platyhelminthes	bilateral	three	absent	foreshadowed in internal organs	absent	anterior ganglia
Annulata	bilateral	three	present	internal and external segmentation coincide	present	brain and nerve ring
Arthropoda	bilateral	three	coelom, a hemocoele	external only	present	more ganglia in brain

on the head are modified for tactile and eating purposes; those on the thorax, for walking and jumping. There are three pairs of thoracic appendages and these are all *uniramous*. This is the extreme reduction in arthropod appendages.

The exoskeleton is heavy with chitin and must be shed before growth can occur. Many of the higher insects substitute a complete metamorphosis for the growth stages, but they are all greatly limited in size by the exoskeleton. This limitation makes it impossible for the insects to accomplish the long life possible to the vertebrates with their internal growing skeleton, but it represents the height of specialization in the teloblast series.

CHAPTER XXVII

SPECIALIZED ORGANIZATION

MOLLUSCS

The molluscs are triblastic, primarily bilateral forms. They are unsegmented, but have a trochophore larval form which relates them with the segmented animals. They are highly organized, with complex respiratory and circulatory systems and, in some groups, a considerable cephalization.

The characteristic for which the molluscan classes are named is the muscular foot. The *Pelecypoda* use the foot for *plowing,* as does the clam. The *Gastropoda* use the foot for *creeping,* as does the snail, and the *Cephalopoda* use the foot for *capturing food,* as does the squid. In that case the organ is divided into long, muscular tentacles which surround the head.

The characteristic by which the molluscs are most widely known is the *shell.* The shell is secreted by an organ called the *mantle* which surrounds the body like an envelope. The space between the mantle and the body is the *mantle cavity.*

In the *Pelecypoda* the shell is *bivalved.* In the *Gastropoda* it is *univalved* and when coiled is coiled spirally to left or right. In the *Cephalopoda* the squids and devilfish have internal horny shells. The shell of the nautilus is external and coiled like a spring, dorsoventrally.

CLAM

The clam is a *bivalved* mollusc, chosen for the general simplicity of the type among a complex group. The description given here will apply equally well to Venus, the hard-shelled clam, and to the fresh-water mussels, Anodonta and Unio. The minor differences are indicated. Unio has been used for the illustrations.

Organization

The two valves of the shell represent the right and left sides of the clam; the hinge of the shell represents the dorsal

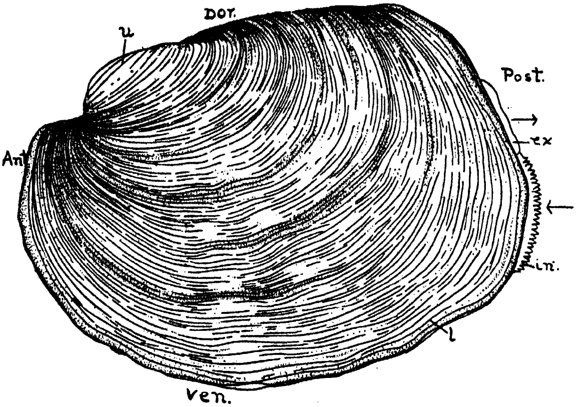

Fig. 279.—Unio. External view showing the left valve and the incurrent and excurrent siphons. *u*, Umbo; *l*, lines of growth; *ex*, excurrent siphon; *in*, incurrent siphon; *Ant*, anterior; *Post*, posterior; *Dor*, dorsal; *Ven*, ventral. The arrows indicate the direction of the water currents. (Drawn by Anne Young.)

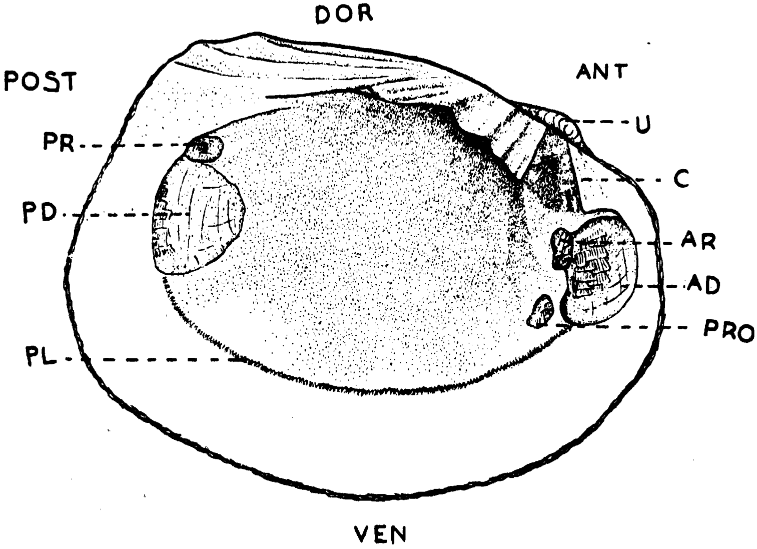

Fig. 280.—Unio. Internal view of left valve. *U*, Umbo; *C*, cardinal tooth; *AR*, anterior retractor muscle scar; *PD*, posterior adductor muscle scar; *PR*, posterior retractor muscle scar; *PL*, pallial line; *POST*, posterior; *ANT*, anterior; *DOR*, dorsal; *VEN*, ventral. (Drawn by Frances Fiske.)

side, and the muscular foot, the ventral side. The mouth is at the anterior end and the anus at the posterior end. The three primary axes of the bilateral animal are thus indicated.

The entire body is enclosed within the mantle cavity, although the muscular foot can be extended between the valves of the shell. In cross-section, the body is seen suspended between the two valves of the shell. In the center is the solid *visceral mass* to which the foot is attached. On either side of the visceral mass, and next to the shell valves hang the flaps of the *mantle.* Between the mantle flaps and the visceral mass hang two pairs of leaflike folds, the *gills,* each composed of two *lamellae* which are continuous on their ventral surfaces. The dorsal surfaces of the *gills* are attached to the mantle on the outside, to the visceral mass on the inside, and to each other in the center, so as to form a W.

Dorsal to the visceral mass is seen the *pericardial cavity,* or perivisceral coelom in which cavity the heart lies; the ventricle is folded about the rectum which passes through the cavity. Ventrally the foot is attached to the visceral mass. It can be extended between the valves and can plow its way through the sand at the rate of one mile a year. It has the shape of a plowshare.

External Structure

SHELL

The shell is composed of three layers: the outer, horny layer, called the *periostracum;* the thick *prismatic* middle layer which is impregnated with calcium carbonate and is the hard part of the shell; and the inner, *nacreous* layer which is lustrous. It is this layer which is used in the manufacture of pearl buttons, and is especially well developed in the mussels and oysters. About 26,000 tons of mussel shells have been taken by the United States Bureau of Fisheries in a single year for the button and novelty industries.

The entire shell is secreted by the mantle. The thick edge secretes the two outer layers, and the entire flat surface secretes the pearly layer. True pearls are secreted by the mantles of oysters and mussels when an irritating object, such as a small organism, lodges on its surface. Japanese scientists have devised a method for encouraging the formation of pearls by inserting spherical objects inside the mantle. These are called "culture pearls" and are often quite perfect.

On the outside, the valves of the shell are marked by lines of growth parallel to the edge and centering around a small anterior area on the dorsal side, called the *umbo*. This is the shell with which the minute adult started out after its metamorphosis, and lines of growth represent intervals of rest between periods of growth.

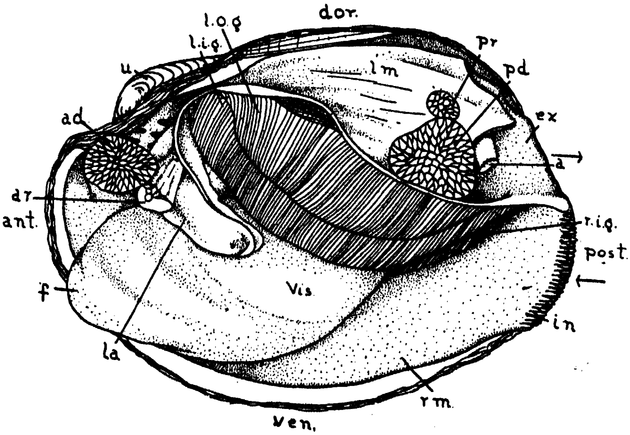

Fig. 281.—Unio. Left valve of shell and left mantle removed to expose the mantle cavity. *u*, Umbo; *l.i.g.*, left inner gill; *l.o.g.*, left outer gill; *r.i.g.*, right inner gill; *lm*, left mantle over the pericardial chamber, the posterior edges cut to expose the intestine; *a*, anus; *ex*, excurrent siphon, left margin removed; *in*, incurrent siphon, left margin removed; *rm*, right mantle; *vis*, visceral mass; *f*, foot; *la*, labial palp; *ar*, anterior retractor muscle; *ad*, anterior adductor muscle; *pr*, posterior retractor muscle; *pd*, posterior adductor muscle; *ant*, anterior; *post*, posterior; *dor*, dorsal; *ven*, ventral. Arrows show the direction of the water currents. (Drawn by Anne Young.)

On the inner, dorsal surface, the ligamentous hinge is found. This is elastic and when the adductor muscles relax the shell snaps open. In Venus and Unio the valves articulate with each other by means of toothlike projections. In Anodonta these are almost completely atrophied.

The inner surface of the valves also shows the scars of the muscle attachments. The two large anterior and posterior scars mark the impressions made by the large *adductor* muscles which hold the shell of the valves together against a pull of

4000 grams. The smaller scars mark the attachments of the *protractor* and *retractor* muscles which extend and retract the foot.

Parallel with the edge of the valve is a mark known as the *pallial line* where the mantle is attached to the shell. In Venus a *pallial sinus* marks the point posteriorly where the two siphons lie.

MANTLE AND MANTLE CAVITY

There are two flaps to the mantle, one lying against each of the shell valves, and attached to the valves at the pallial line. The thick edge which secretes the two outer layers of the shell is free. At the posterior end the ventral edges of the mantles fuse for a short distance, then separate and fuse again twice, to form the dorsal and ventral *siphons*. In Anodonta and Unio, the siphons are mere flaps of tissue, and the edges of the ventral siphon are fringed. In Venus, both the siphons have heavy walls and project some distance from the mantle.

A transverse septum between the two siphons divides the mantle cavity into two chambers. The ventral chamber is the large, *branchial* one in which lie the visceral mass and gills; the dorsal chamber is the *cloacal* one, into which open the anus and all other excretory apertures.

Water enters the mantle cavity through the ventral siphon and is forcibly ejected, together with the waste materials, through the dorsal siphon.

General Anatomy

By removing the right valve of the shell and the right mantle, the body of the clam will be disclosed, lying in the left valve with the anterior end toward the observer's left.

Organs of Respiration.—The two gills of the right side lie over the visceral mass. Each gill is in origin but a single *ctenidium*, which is the typical respiratory organ of the snails and squids. Each consists of two *lamellae*, united ventrally and open dorsally. The dorsal lamella of each gill is, however, united to the organ adjacent to it so that in cross-section, the gills form a W. The outer lamella of the outer gill is attached to the mantle cavity, and its inner lamella is attached to the outer lamella of the inner gill. The inner lamella of the inner gill is attached to the visceral mass. (See Fig. 282.)

The lamellae are also joined together by vertical partitions, the *interlamellar junctions*, which divide the space between the lamella into parallel

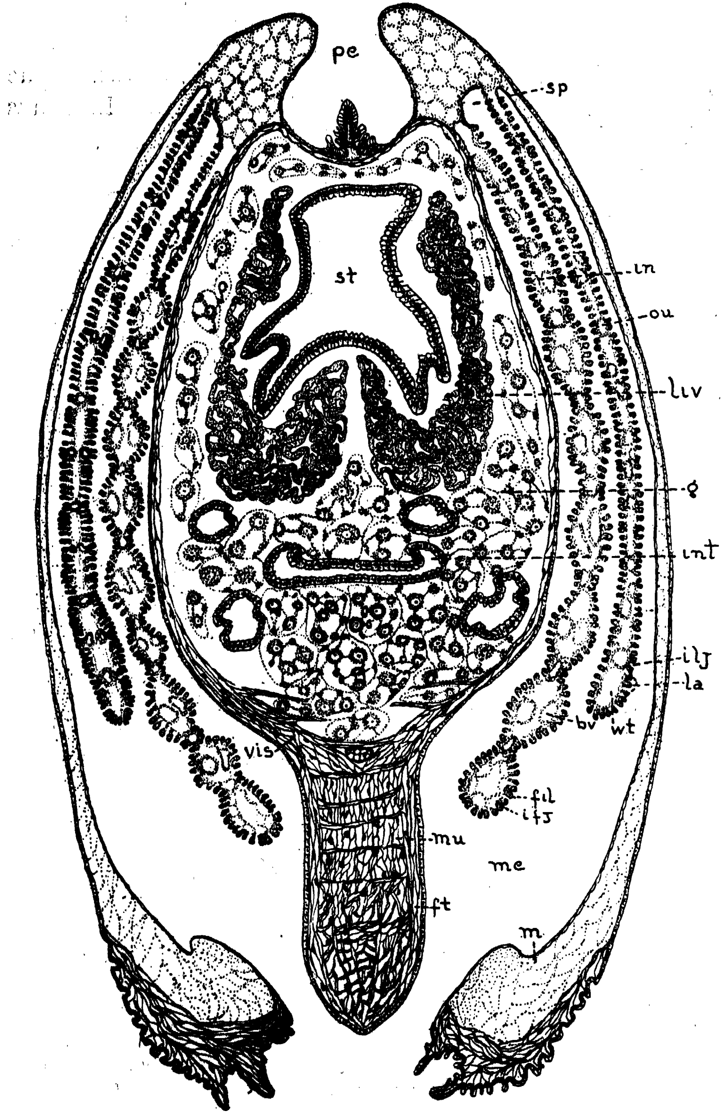

Fig. 282.—Clam. Cross-section through a region anterior to the heart. *pc*, Pericardial cavity; *sp*, suprabranchial passage; *st*, stomach; *in*, inner gill; *ou*, outer gill; *liv*, liver; *g*, gonads; *int*, intestine; *ilj*, interlamellar junction; *la*, lamella; *wt*, water tube; *bv*, blood vessel; *fil*, filament; *ifj*, interfilamentar junction; *mu*, muscle; *ft*, foot; *mc*, mantle cavity; *m*, mantle; *vis*, visceral mass. (Original drawing by Elizabeth Drumtra.)

water tubes. These open dorsally into a *suprabranchial passage* which opens into the cloacal chamber. A blowpipe inserted into this opening will demonstrate these passages.

On microscopic examination the lamellae may be seen as a delicate latticework. Parallel to the interlamellar junctions are the *gill filaments,* connected to each other by cross partitions, the *interfilamentar junctions.*

Cilia on the gill filaments create currents which pass the water into the water tubes. The course of the water which enters through the ventral siphon is through the branchial chamber to the filaments where the cilia direct it to the water tubes and thence to the suprabranchial passage, the cloacal chamber, and out through the dorsal siphon.

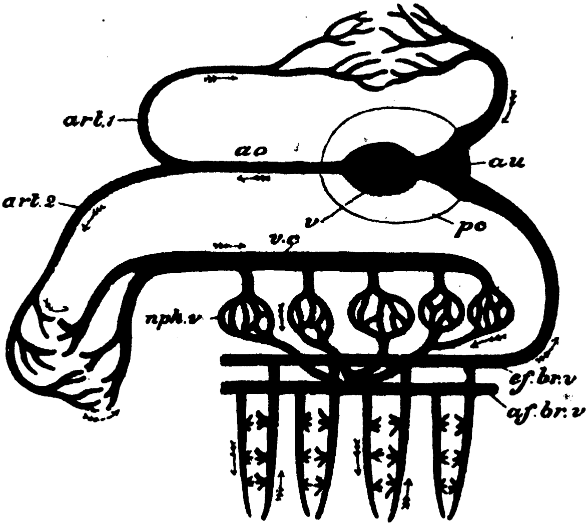

Fig. 283.—Diagram of the circulatory system of a fresh water clam. *af. br. v.,* Afferent branchial veins; *ao,* aorta; *art 1,* artery to mantle; *art 2,* artery to body generally; *au,* auricle; *ef. br. v.,* efferent branchial veins; *nph. v.,* nephridial veins; *pc,* pericardium; *v,* ventricle; *v.c.,* vena cava. The arrows show the direction of the current. (Reprinted by permission from Parker and Haswell: Zoology. Published by The Macmillan Co.)

The outer gill serves also as a brood chamber in the female, the young embryos developing between the lamellae. A few may be found in the inner gill, but this is not usual.

Organs of Circulation.—The respiration of the mollusc is intimately related to its circulatory system so that the fresh oxygen is speedily carried from the gills to all parts of the body. It is largely a closed system, although in the visceral mass there are many open sinuses, called *lacunae,* which are virtually a *hemocoele.* Thus the mollusc has, in addition to its reduced perivisceral coelom in the pericardial cavity and in the ducts of the reproductive organs, a secondary coelom resembling that of the arthropods which is entirely a hemocoele.

The heart consists of a thick-walled *ventricle,* which is wrapped about the rectum, and two lateral *auricles,* which are triangular and thin-walled. This is typical of the heart in all molluscs.

From the ventricle arteries run to both ends of the body, the *anterior artery* running dorsal to the rectum, and the *posterior artery,* ventral to the rectum. By contraction of the ventricle, blood is sent in both directions at one time. From the arteries the blood reaches all the organs of the body. In the visceral mass and in the soft upper region of the foot, the vessels ramify into extensive networks in which many of the walls disappear, thus forming sinuses, or *lacunae.* These constitute the hemocoele mentioned in a preceding paragraph. From the open sinuses the blood is collected into a vein, the *vena cava,* which lies between the nephridia and leads directly into them. From the nephridia the blood moves to the gills where it circulates in closed vessels, entering first the afferent branchial vein. From this vessel it ramifies through the whole gill system, passing through the interlamellar junctions, the gill filaments, and the interfilamentar junctions to the efferent branchial vein, and thence to the auricles. In passing through the gills, the blood has been in contact with the water of the branchial chamber through the water tubes,

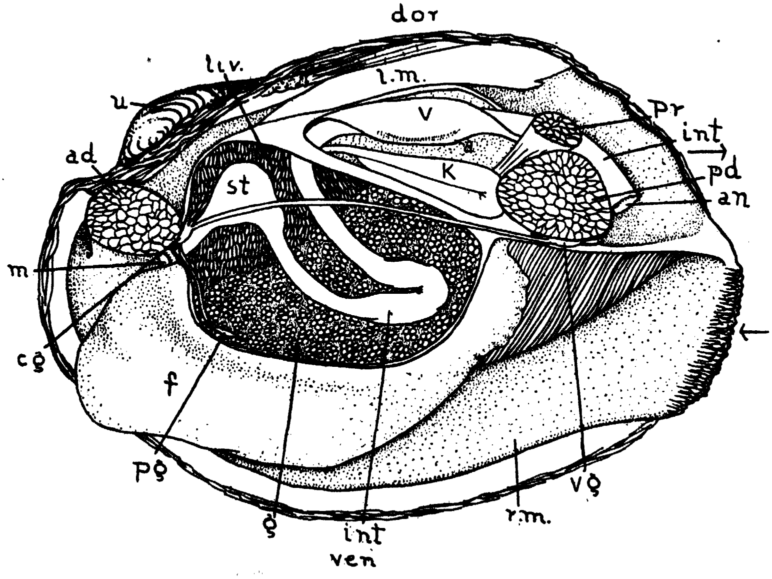

Fig. 284.—Unio. Dissection of visceral mass. The left mantle and gills have been removed, exposing both the mantle cavity and the pericardial chamber. *u,* umbo; *liv,* liver; *l.m.,* remnant of left mantle; *v,* ventricle of heart wrapped about the rectum; *a,* auricle; *k,* kidney; *m,* mouth; *st,* stomach; *int.* intestine; *an,* anus; *g,* gonads; *f,* foot; *cg,* cerebral ganglion; *pg,* pedal ganglion; *vg,* visceral ganglion, with connecting commissures. Other labels as in preceding figure. (Dissection and drawing by Anne Young. The nervous system was added from a wall chart.)

and the fresh oxygen is thus brought direct to the heart. The auricles pass the blood into the ventricle for redistribution.

Organs of Digestion.—On either side of the mouth hang two small, triangular flaps, the *labial palps.* The external palps unite in front of the mouth to form an upper lip, and the internal palps unite behind the mouth to form a lower lip. The palps are ciliated externally, and on the surfaces facing each other are furrows which lead into grooves between the palps. These grooves lead directly into the mouth cavity, and since the palps have a sensory function, they thus capture and convey to the mouth any small organisms brought into the branchial chamber through the ventral siphon.

The *mouth* leads into an *esophagus* which passes dorsally into the stomach, a large organ which lies embedded in the soft tissues of the visceral mass. It can be disclosed only by very careful dissection. It lies just over the anterior adductor muscle and is surrounded by blood sinuses and a soft, digestive gland of large proportions, the *liver.* The liver secretes digestive juices into the stomach through several short ducts. The *intestine* passes ventrally into the soft upper region of the foot where it makes several coils, and then passes up to the pericardium. Here it becomes the *rectum.* It makes a sharp turn to the right and runs directly through the pericardium to the anus, which opens into the cloacal chamber. Midway in its passage through the pericardium, the ventricle of the heart is wrapped about it.

Organs of Excretion.—Two dark colored *nephridia* lie on either side, just ventral to the pericardium. These are comparable in structure to the nephridia of the earthworm, and consist each of a ventral glandular portion which opens into the pericardium by means of a ciliated slit, and a dorsal, thin-walled tube which opens into the cloacal chamber through the renal aperture. These are sometimes referred to as the *organs of Bojanus.*

Organs of Conduction.—There are three pairs of ganglia: the *cerebral ganglia,* or brain, lying just behind the anterior adductor muscle above the mouth, the *visceral ganglia* on the ventral surface of the posterior adductor muscle, and the *pedal ganglia* buried near the base of the foot.

Each of the cerebral ganglia sends out three large commissures: the *cerebrovisceral* which goes to the visceral ganglia, the *cerebropedal* which goes to the pedal ganglia, and the *pallial nerve* which goes to the mantle. A commissure also unites the two cerebral ganglia, and these, with the cerebropedal commissures, complete the ring around the mouth which is typical of all invertebrate nervous systems. The visceral and pedal ganglia are small, pinkish masses with nerves radiating in all directions.

SUMMARY OF THE PHYSICAL FUNCTIONS OF BEHAVIOR

Sensation: Labial palps.

Conduction: Cerebral, visceral, and pedal ganglia with connecting commissures.

Locomotion: Plowshare foot.

Protection: Bivalved shell secreted by mantle.

SUMMARY OF THE CHEMICAL FUNCTIONS OF NUTRITION

Digestion: Labial palps, mouth, esophagus, stomach, liver, intestine, rectum, anus.

Respiration: Two pairs lamellate gills.

Circulation: Partially closed vascular system; heart with one ventricle and two auricles; sinuses form a hemocoele in the visceral mass.

Excretion: A single pair of nephridia.

Reproduction

The sexes are separate. The gonads, male and female, are much alike and consist of a pair of whitish masses embedded in the visceral mass. The external openings are a pair of minute pores, one on each side of the visceral mass, just below and anterior to the renal aperture.

The sperm pass out through the dorsal siphon of the male in the early summer and are drawn into the ventral siphon of the female. The eggs are fertilized in the cloacal chamber, where the mature eggs congregate, and extrude from the genital aperture. In the fresh water clams the fertilized eggs are passed into the cavities between the lamellae of the outer gills, where the embryo develops, distending the gill enormously.

In only a few of the bivalves has the development been followed in detail but in the early stages it is apparently similar in all. The cleavage is spiral and the *trochophore* larva which develops is very similar to that of the annelids, except that it possesses the characteristic molluscan structure, the shell gland. After a short, free swimming existence, the trochophore is transformed into a *veliger* by the development of a bivalve shell, and a certain amount of lateral compression.

Metamorphosis in Unio

In the marine bivalves the metamorphosis of the adult takes place rapidly, but in Unio there is a prolonged parasitic stage for which special preparation is made. The veliger becomes a *glochidium*. The two valves of the shell are triangular and are hinged at the base, the ventral edges curving in to form hooks. In place of a foot, it has a gland which secretes a long, sticky thread, the *byssus*, very similar to the threads with which the marine mussels attach themselves to the rocks.

These larvae are ejected through the dorsal siphon into the water, and if they come in contact with a small fish, the byssus will be extended and fastened by its sticky secretion to the skin of the fish. The glochidia fasten their hooks into the flesh and become embedded by the inflammation of the skin. They lead a parasitic existence, absorbing the juices of the host until metamorphosis takes place; then they drop off to lead an independent life. The shell of the glochidium forms the umbo of the adult shell.

AFFINITIES OF THE MOLLUSCS

The affinities of the molluscs are difficult to establish because of their complete loss of metamerism. The larva is a typical trochophore in its early stages. The appearance of a shell gland and the absence of the elongation stage distinguish it from the annelid type. Some would trace the molluscs back to the flatworms, but since the internal repetition of organs had started in that group, this hardly explains the lack of metamerism. Proponents of the trochophore theory trace them back to the trochophore-like ancestor, but the molluscs show certain resemblances to the earthworm in the type of nephridium, and to the leech in the possession of a hemocoele in addition to the perivisceral coelom. The highly specialized respiratory and circulatory systems are far from being primitive, and those that have any cephalization have a more advanced type than that shown in any annelids. It seems safer, therefore, to consider them a specialized group that has abandoned metamerism in the entire group, much as the head has been abandoned in the bivalves. Both of these losses may be adaptations to a specialized mode of life.

ECHINODERMS

The Echinoderms are triblastic, coelomate animals with organs and systems characteristically in five divisions. They have spiny skins and, usually, a calcareous skeleton of regularly arranged plates. A layer of epithelial cells over the plates make the skeleton internal. It is not a typical endoskeleton, however, since it is formed from ectoderm cells.

The *Asteroidea* include the starfishes; the *Echinoidea,* the sea urchins; the *Holothuroidea,* the sea cucumbers; and the *Crinoidea,* the sea lilies.

STARFISH

The starfish, Asterias, is an echinoderm with five rays radiating from a central disc. The body is flattened oral-aborally, oral surface down. Mouth and anus are at opposite ends of the very thin disc, and the coelom and organs extend out into the five rays.

A hard, porous plate on the aboral surface separates the disc into two bilateral halves. The plate is the *madreporite.* The two rays enclosed by the plate are called the *bivium,* the other three, the *trivium.* This bilateral symmetry is superficial only.

There is no cephalization.

External Structure

The starfish has a spiny skeleton of calcareous plates, or *ossicles.* These are regularly arranged around the mouth and on either side of the *tube feet,* but on the rest of the body they are scattered, thus allowing free movement of the rays. The ossicles have muscle attachments. The skeleton is covered over by a layer of epithelial cells.

On the aboral surface the *spines* are especially numerous. These are short and blunt, and are covered by a layer of ectoderm cells. Around the bases of the spines are scattered *pedicellariae;* minute pinchers which open and close by muscular action. These protect the soft outgrowths of the body wall, called the *dermal branchiae,* by biting off any foreign matter or minute organisms which light on the surface.

On the oral surface, the *mouth* occupies a central position, surrounded by a membranous *peristome. Ambulacral grooves* extend down the center of each ray, and on either side of the grooves regular rows of *tube feet* are arranged. The muscles of the ossicles on either side of the grooves make it possible to close the grooves and thus conceal the tube feet.

Internal Structure

If the aboral surface be removed from the trivium and central disc, all the internal organs can be exposed without injuring the madreporite.

Coelom

The *coelom* of the starfish is extensive and is divided into two regions: the *perivisceral coelom* which surrounds the organs in the central disc and in the five rays, and the *water vascular system.*

The perivisceral coelom is filled with a fluid of the composition of sea water together with some albuminous material secreted by the lining, or *peritoneum.* The peritoneum, also, buds off amoeboid cells, known as *amoebocytes.* These wander about in the coelomic fluid collecting waste materials which they carry to the dermal branchiae and so to the outside. Cilia on the wall of the peritoneum create currents which keep the coelomic fluids in motion.

The water vascular system, which is peculiar to the echinoderms, has sensory, excretory, and motor functions. From the madreporite a sinuous *stone canal* extends down to a *ring canal* which circles the central disc. *Radial canals* extend out from the ring canal into each of the five rays where they lie just above the ambulacral grooves. The tube feet are branches of the radial canals. They pass through pores in the ossicles to the outside. Internally, the tube feet have bulblike sacs, the *ampullae,* which branch into the perivisceral coelom.

Nine vesicles, called "*Tiedemann's bodies*" arise from the ring canal. These form additional amoebocytes which assist in the excretory function. In some starfishes *polian vesicles* are also formed on the ring canal, but this is not true of Asterias. When present, their contraction forces water from the ring canal into the five radial canals.

The tube feet have a sensory function, but their most unique function is that of locomotion. The force of the suction is so great as to exert a considerable pull, sufficient, in fact, to open the valves of an oyster.

Cilia in the grooves of the madreporite force the sea water into the stone canal, whence it proceeds through the ring canal

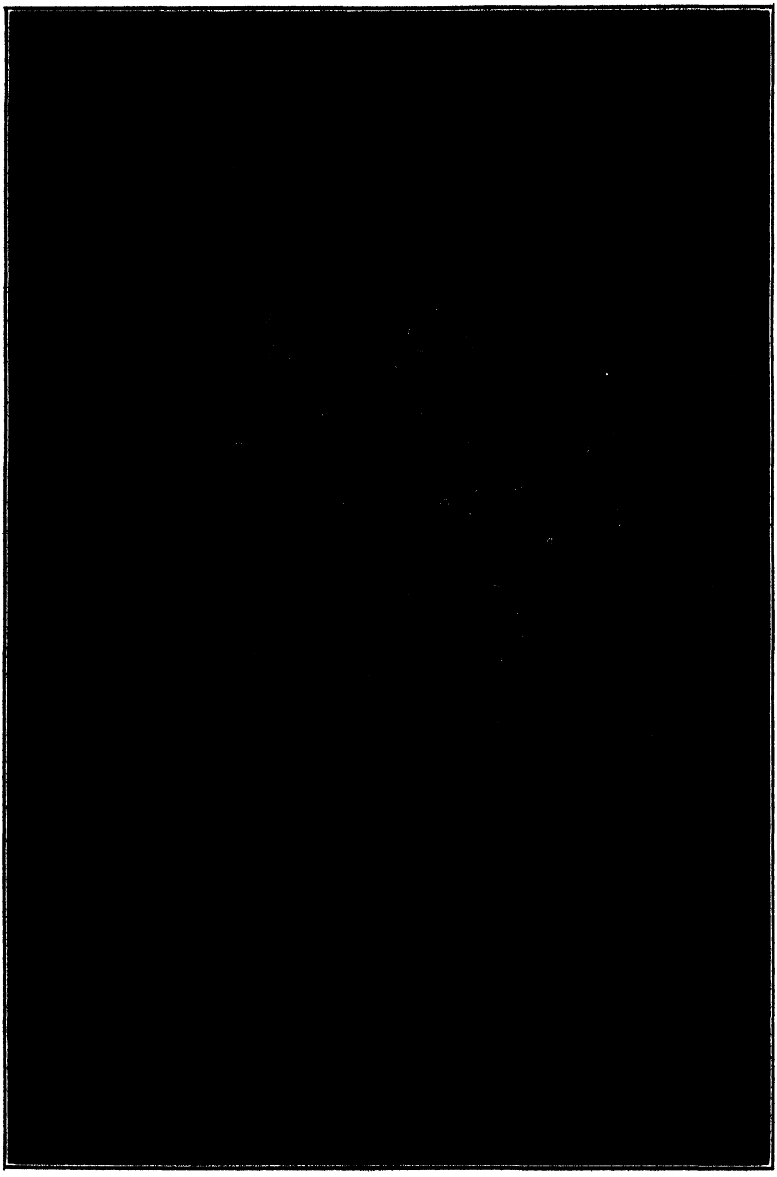

Fig. 285.—Home of the starfish. Note periwinkles and brown alga (Fucus). Photographed from life by M. C. Dickerson. (Courtesy of the American Museum of Natural History.)

and radial canals to the tube feet. Some of the fluid is drawn into the ampullae where it remains until a stimulus reaches the ampulla. Any excess water passes to the outside slowly through the tube feet at all times, but since there is a continuous flow of

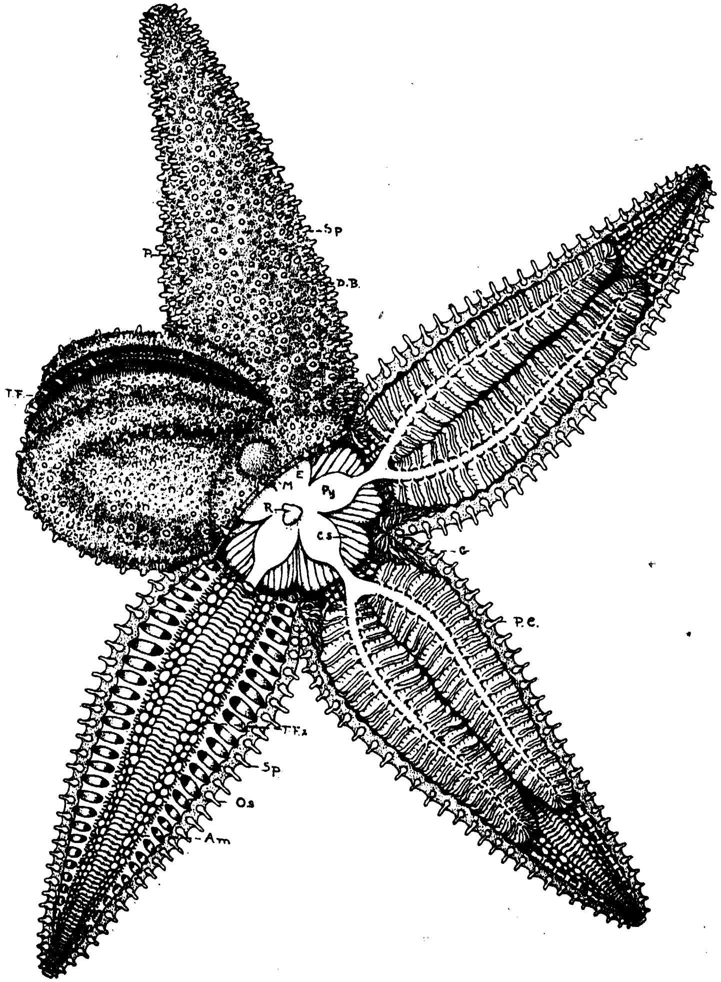

Fig. 286.—Dissection of the starfish, Asterias. The aboral surface has been removed from the rays of the trivium, and a portion of the disc. One ray of the bivium is turned back to show the oral surface, and the organs have been removed from one ray of trivium to show the skeleton. *Sp*, Spine; *P*, pedicellariae; *D.B.*, dermal branchiae; *T.F.*, tube feet; *T.F.*$_2$, arrangement of tube feet in skeletal ray; *Os*, ossicle; *Am*, ambulacral groove; *E*, eyespot on end of ray; *M*, madreporite; *Py*, pyloric sac; *C S*, cardiac stomach; *R*, rectal caeca; *G*, gonads; *P.C.*, pyloric caeca. (Dissection and drawing by Anne Young.)

water from the madreporic plate, the ampullae are amply supplied. When the muscles of the ampullae contract, the stored water is forced down into the tube feet. The suckers on the end of the feet are then extended and brought into contact with the surface over which they are walking. The pressure of the water makes it difficult to tear them loose when in this position, and the longitudinal muscles of the feet contract to pull the whole body forward. The liquid in the tube feet is then drawn back into the ampullae and the feet are loosened. The progress is necessarily slow.

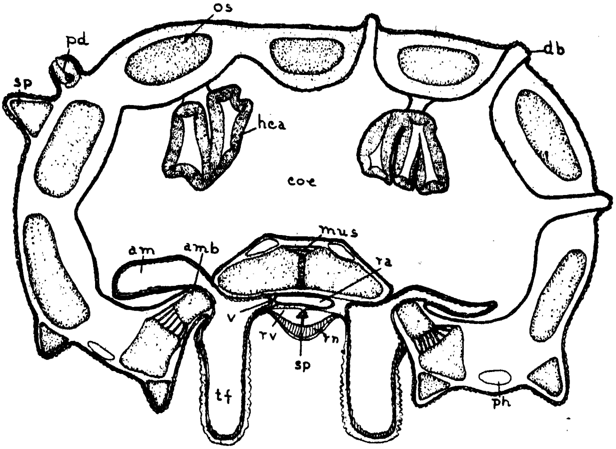

Fig. 287.—Starfish. Cross-section through ray. *Sp*, Spine; *pd*, pedicellaria; *os*, ossicle; *db*, dermal branchia; *hca*, hepatic caeca; *coe*, perivisceral coelom; *am*, ampulla; *amb*, ambulacral ossicle; *mus*, muscle; *ra*, radial canal separated by a valve (*v*) from the tube foot (*tf*); *sp*, septum dividing the radial blood vessel (*rv*); *rn*, radial nerve; *ph*, perihemal space. (Original drawing by Elizabeth Drumtra.)

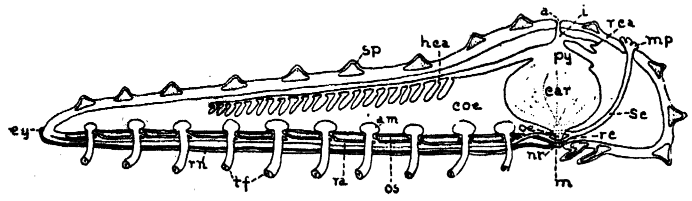

Fig. 288.—Starfish. Longitudinal section through the disc and one ray. *Sp*, Spine; *hca*, hepatic caeca; *a*, anus; *i*, intestine; *rca*, rectal caeca; *mp*, madreporic plate; *py*, pyloric sac; *car*, cardiac stomach; *sc*, stone canal; *rc*, ring canal; *oe*, esophagus; *nr*, nerve ring; *m*, mouth; *coe*, perivisceral coelom; *am*, ampulla; *os*, ambulacral ossicle; *ra*, radial canal lying in the ambulacral groove; *tf*, tube feet; *rn*, radial nerve; *ey*, eyespot. (Original drawing by Elizabeth Drumtra.)

When an oyster or mussel shell is to be opened, the starfish attaches its tube feet to the shell and then rises on the tips of the five rays so that the pull of the tube feet is at right angles to the valves of the shell. The shell can be maneuvered into position so that the gape of the valves will face the mouth of the starfish. It has been demonstrated that while a bivalve can resist a sudden pull of as much as 4000 grams, it will yield to a long continued pull of as little as 900 grams. It is the steady pull exerted by the tube feet, therefore, that forces the muscles of the bivalve to relax and the valves to gape slightly, thus admitting the stomach of the starfish. The pull of the tube feet has been demonstrated to be as great as 1350 grams.

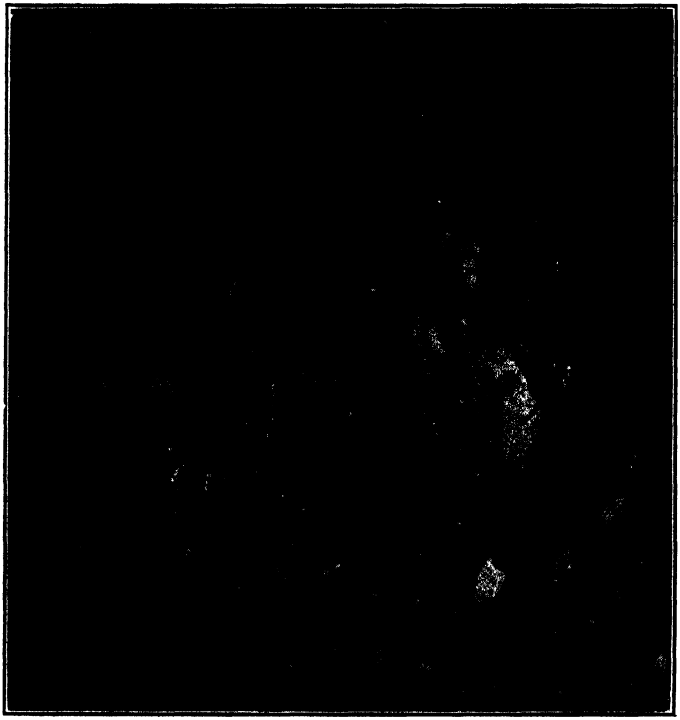

Fig. 289.—Starfish attacking oyster. (Courtesy of the American Museum of Natural History.)

Organs of Digestion.—The digestive tract is very short, owing to the flattening of the body. A short esophagus opens into a thin-walled sac, the *cardiac stomach,* which opens into a *pyloric sac.* The pyloric sac leads centrally into a short rectum which connects with the anus on the aboral surface, and laterally into five tubes extending into the five rays. In the rays, these tubes divide into two branches with numerous green pouches on the sides. These are the *pyloric* or *hepatic caeca.* Two brown pouches, the *rectal caeca* branch off from the rectum.

When eating an oyster, the valves of which have been forced open by the tube feet, the membraneous peristome is expanded by the fluids underneath and the cardiac stomach is partially everted through the mouth. The everted stomach is inserted between the valves of the oyster and applied directly to the unprotected organs. Digestion proceeds until nothing is left of the oyster but the empty shell.

Very small animals can be swallowed by the starfish, in which case the shell is later everted through the mouth. In general, however, the food of the starfish is digested outside of the body and very little undigested food enters the digestive tract.

The digestive fluids are secreted by the lining of the digestive sacs. The pyloric caeca and the pyloric sac secrete the enzymes and the cardiac sac, the mucous secretion. The rectal glands secrete a brown liquid which is probably excretory in function. Very little material passes through the anal opening.

Organs of Respiration and Excretion.—Oxygen and carbon dioxide are exchanged through the *dermal branchiae* which are small sacs growing out of the body wall. The amoebocytes in the coelomic fluid make their way to the outside through the dermal branchiae; therefore, their function is excretory. The Tiedemann's bodies aid in excretion also.

Organs of Conduction.—There are many nerve cells lying in among the ectoderm cells, but the main nervous system consists of a nerve ring around the mouth with radial nerves running along each of the ambulacral grooves and ending in a mass of pigment, which, owing to its function as a light perceiving organ, is called an eye.

Behavior

The reactions of the starfishes are complex. They are more active at night than in the daytime. They have been credited with a form of memory by Jennings who claims to have taught certain starfishes to turn over on a particular ray when placed on the aboral surface. This righting reaction is quite definite and is accomplished by the bending of the entire ray. This motion is due to the contractions of the muscle fibers attached to the scattered ossicles.

The starfish has a limited power of regeneration, having been known to regenerate the entire body from a single ray with a piece of disc attached. In general, however, regeneration is a very slow process.

The starfish may also break off a ray if injured and regenerate a new one. This is called autotomy.

SUMMARY OF THE PHYSICAL FUNCTIONS OF BEHAVIOR

Sensation: Tube feet; light-perceiving pigment masses, dermal branchiae.

Conduction: Nerve ring and five radial nerves, scattered nerve cells.

Locomotion: Tube feet; muscular bending of rays.

Protection: Calcareous ossicles; spines; pedicellariae.

SUMMARY OF THE CHEMICAL FUNCTIONS OF NUTRITION

Digestion: Mouth, esophagus, cardiac and pyloric sacs of the stomach; pyloric caeca, rectum, anus.

Respiration: Dermal branchiae.

Circulation: Cilia on peritoneum create currents in coelomic fluid.

Excretion: Rectal caeca and anus; amoebocytes; dermal branchiae; Tiedemann's bodies.

Reproduction

The sexes are separate. Close to the base of each ray, at the intersections of the two adjoining rays, lie two gonads, male or female. These are profusely branched and connected with minute pores on the aboral surface between each two rays.

The eggs are fertilized in the water, and undergo typical development with regular and equal cleavage (see Chapter XIII). An embryonic digestive tract, called the archenteron, forms by the inpushing of the cells at one pole. The opening is called the blastopore. It forms the larval anus, the archenteron pushing around to the ventral side to form a larval mouth.

The larva of the starfish is called a *bipinnaria*. It swims by means of two circlets of cilia which separate the body into a preoral and postoral region. The stomach is a flask-shaped organ. From the right and left sides of the stomach are constricted off two pouches, called water tubes. These are the archenteric pouches characteristic of the enterocoele series and are the rudiments of the true coelom.

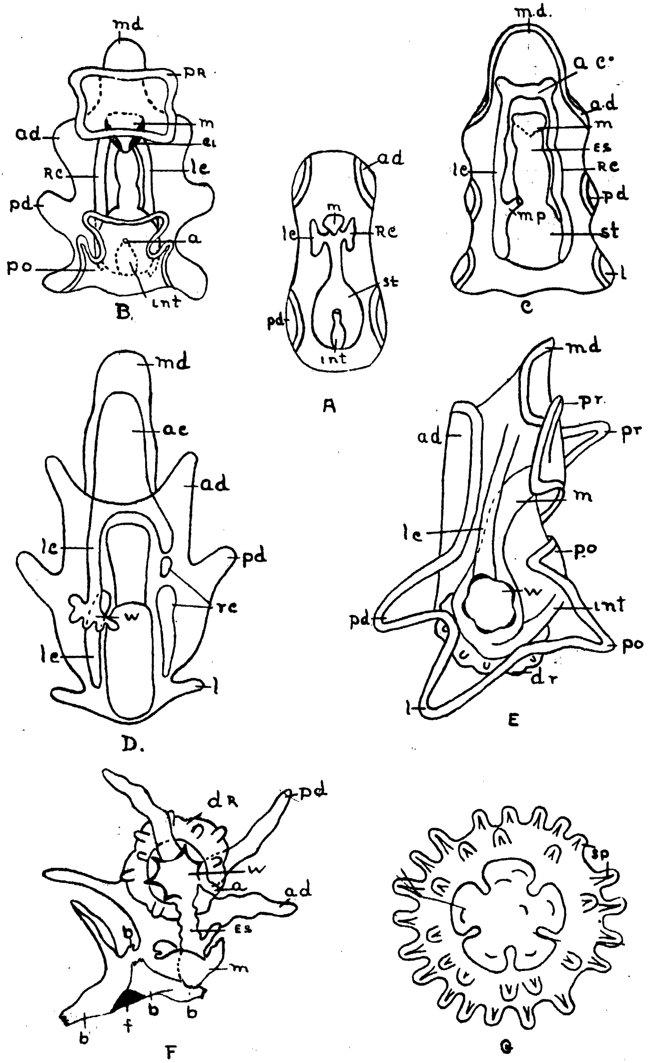

Fig. 290.

(See opposite page for legend.)

The left pouch sends out a tube which unites with the dorsal integument to form an external opening, the madreporic pore. Occasionally the larvae form a similar pore on the right side, indicating the original bilateral symmetry of the organism.

On the left pouch, also, there develops a five-lobed outgrowth which develops into the water vascular system. Each lobe grows out to become one of the radial tubes of the adult system, the central portion of the left water tube becoming the ring canal.

In Asterina the preoral lobe forms an organ of temporary attachment, and contains a portion of the coelom.

The metamorphosis of the bilateral larva into an adult with radial symmetry is accomplished by the grouping of the organs about the five-lobed outgrowth from the water tube. This lies on the left side, at right angles to the larval axis. The larval stomach persists as the pyloric stomach, branching off the caeca into the five arms. The cardiac stomach develops as a new growth from the side of the pyloric stomach, and a new mouth opens on the ventral surface inside the ring canal. The rectum is formed by the shortening of the larval intestine, and a new anus opens on the dorsal surface. The dorsal integument forms the five rays which eventually cover the tubes.

When the metamorphosis is complete, the starfish pulls itself free from the temporary disc of attachment. The disc is pulled out into a long, filamentous stalk which breaks to set the adult free.

Fig. 290.—Development and metamorphosis of the starfish. *A*, Dorsal view of early ciliated larva showing ciliated bands, and left and right archenteric pouches. *B*, Ventral view of bipinnaria larva showing the extension of the left and right archenteric pouches. *C*, Dorsal view of the same larva showing the left madreporic pore and water tube, and the fusion of the left and right archenteric pouches to form an anterior coelom. *D*, Dorsal view of an older larva showing the budding of the five water tubes from the left coelom. *E*, Left side view of a still older larva showing the water vascular system developing from the water tubes, and the rays of the adult starfish developing on the dorsal side. *F*, Brachiolaria larva in process of metamorphosis. The larva has settled on the preoral region which is greatly shortened. *G*, Aboral view of a young starfish showing the developing spines.

m, Mouth; *es*, esophagus; *st*, stomach; *int*, intestine; *a*, anus; *lc*, left archenteric pouch; *rc*, right archenteric pouch; *ac*, anterior coelom; *mp*, madreporic pore and water tube; *w*, five water tubes of the water vascular system; *dr*, dorsal surface developing rays; *pr*, preoral ciliated band; *po*, postoral ciliated band; *ci*, adoral ciliated band; *md*, median dorsal arm; *ad*, anterodorsal arm; *pad*, posterodorsal arm; *l*, lateral arm; *dr*, dorsal rays of young starfish; *b*, brachiolar arms; *f*, point of fixation; *sp*, spines. (Modified from Wilson, and McBride. By permission, The Macmillan Co.)

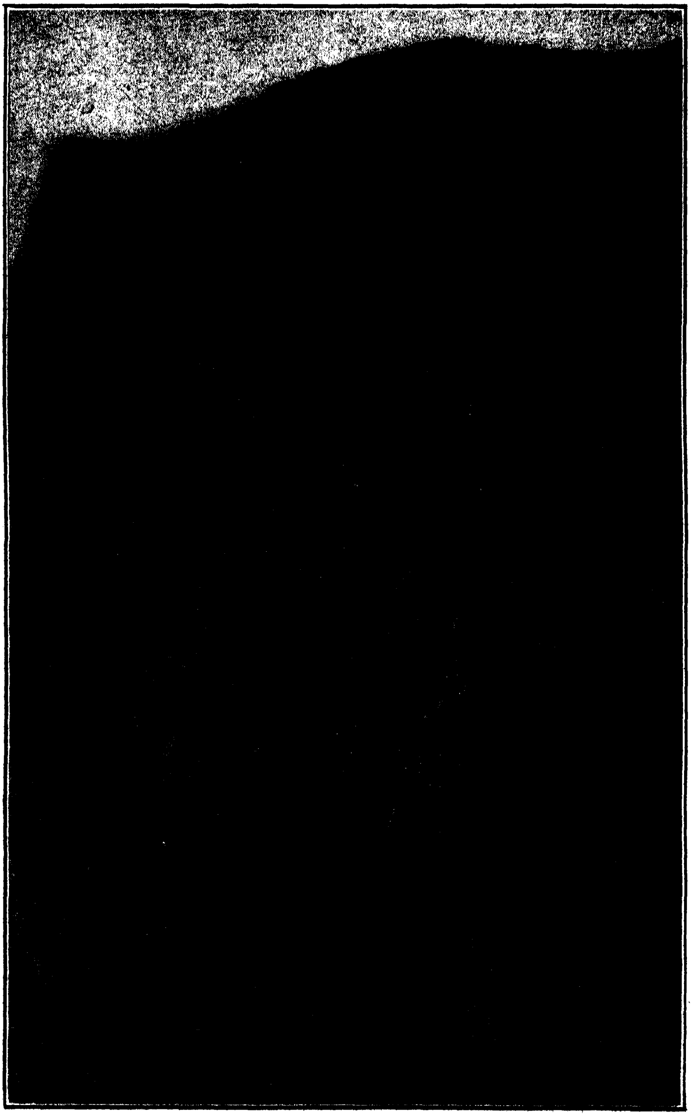

Fig. 291.—Sea lilies on limestone slab from Jerusalem Hill, Litchfield, N. Y. (Courtesy New York State Museum.)

AFFINITIES OF THE ECHINODERMS

The complicated nature of the coelom, the muscular development, and the complexity of the reactions, all point to the affinity of the echinoderms with the higher invertebrates. The bilateral larva and the symmetry of its early development indicate a previous bilateral organization, and such bilateral types are found, according to some authors in the fossil cystoids which existed in the early Paleozoic Era, from the Silurian to the Carboniferous. The Cystoids possess a pronounced radial arrangement in spite of their bilaterality. This probably shows that the earliest forms to adopt the radial habit, retained much of their ancestral bilateral symmetry.

The radial symmetry of the echinoderm is believed to be the result of a previous stalked condition, and such a condition is indicated in the temporarily stalked condition of the larva. Stalked echinoderms flourished during the Paleozoic Era from the Cambrian to the Carboniferous, and constitute the group known as the sea lilies (see Fig. 291). They often attained an enormous size. A few stalked forms exist today. The Japanese sea lilies have long permanent stalks. Antedon is a modern sea lily which retains only a small part of the stalk in the adult condition. The stalked forms are called the crinoids. It is probable, therefore, that the stalked ancestors of the echinoderms were derived from a previous bilateral ancestor.

The close resemblance of the bipinnaria larva of the starfish to the tornaria larva of Balanoglossus (Dolichoglossus), the prochordate, indicates a relationship with the vertebrates. Even though the chordates have developed a very marked internal segmentation, the embryonic development is a strong argument for this connection with the unsegmented invertebrates.

CHAPTER XXVIII

CHORDATE ORGANIZATION

General

The organization of the chordates, in spite of the variety and complexity of the individuals, is so much more uniform than that of the invertebrate phyla that they are classed as a single phylum, the Chordata. With the exception of the prochordates, which are soft bodied and differ widely among themselves, there is remarkable unanimity of structure. At some time during the life history of all there will be found:

1. An axial supporting rod, the *notochord.*
2. Slits in the pharynx wall which open to the outside through the neck, the *gill slits.*
3. A hollow, dorsal *nerve cord.*

This position of the nerve cord is the exact reverse of that in the invertebrates where it lies within or against the ventral wall, and is merely a double, ganglionated cord.

In addition, chordates are triblastic, bilateral, coelomate animals with a specialized, internal metamerism. The mesoderm is formed from the digestive tract or from the lips of the blastopore (embryonic mouth). The origin of the chordates from the invertebrates, therefore, is difficult to establish. On the basis of embryonic development, however, they are here considered as offshoots from the enterocoele series of invertebrates.

Structure

Except in the prochordates the notochord is either partially or wholly replaced by cartilaginous or bony vertebrae from which the familiar term vertebrate is derived. The body is divided into *head, trunk,* and usually a postanal *tail.* The head in most cases is separated from the trunk by a neck. There are two pairs of lateral appendages supported by cartilage or bone. These are the thoracic, or *pectoral,* appendages, and the abdominal, or *pelvic,* appendages. In aquatic forms they are called *fins;* in terrestrial forms, *limbs.* In rare cases they are absent.

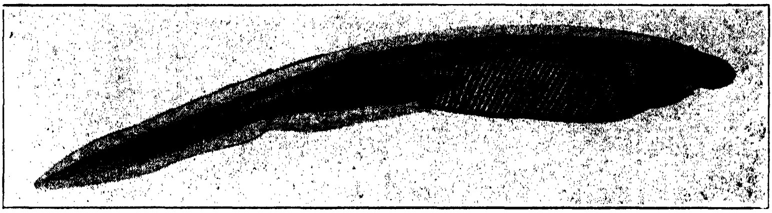

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Fig. 292.—*Amphioxus lanceolatus,* a prochordate, showing the three typical chordate structures. The gill slits show plainly in the pharynx region, and the notochord lies ventral to the nerve chord, and extends slightly beyond it at the anterior end. An hepatic caecum extends forward from the digestive tract, and a fold of skin extends the entire length of the dorsal surface, and forward around the tail to a point slightly anterior to the anus. This forms the dorsal, caudal, and ventral fins, and is supported by fin rays. The paired metapleural folds do not show. Amphioxus is a burrowing form, and in many respects differs from the higher vertebrates. Photomicrograph of a young specimen, stained and cleared. (Courtesy Albert E. Galigher.)

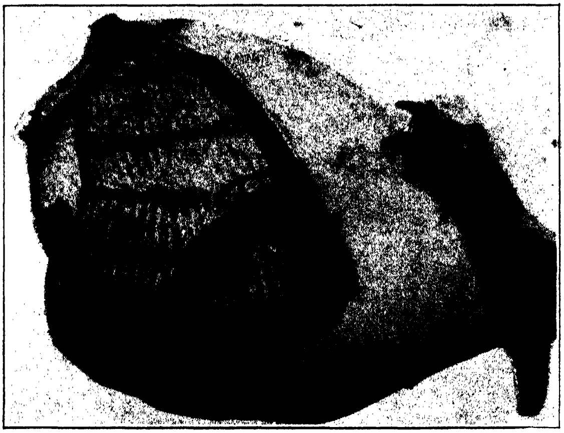

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Fig. 293.—Perophora, a tunicate. Photograph showing siphons gill slits, and digestive tract. (Courtesy Albert E. Galigher.)

Coelom

The coelom of vertebrates is an unsegmented cavity lined by a mesodermal tissue, the *peritoneum.* Double folds of peritoneum grow in around all visceral organs, forming mesenteries which anchor the organs in place. The organs cannot really be considered to be inside the cavity, therefore, since

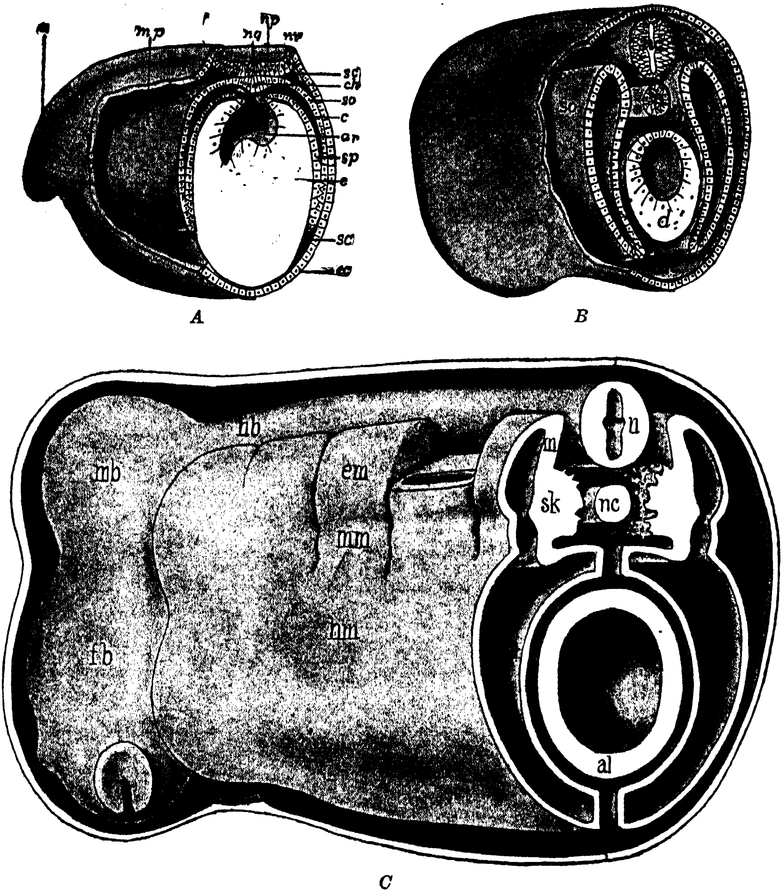


Fig. 294.—Stereograms of the anterior end of developing vertebrates.

A, Early stage showing the origin of the nervous system from the ectoderm, and the origin of the notochord and mesodermal pouches from the region of the archenteron (primitive digestive tract). *a*, Anterior end; *ar*, archenteron; *c*, coelom; *ch*, notochord; *ec*, ectoderm; *mp*, mesodermal pouch; *ng*, primitive groove; *np*, neural plate; *nr*, neural folds; *sc*, segmentation cavity; *so*, somatic, and *sp*, splanchnic wall of coelom.

B, Later stage showing the relation of the archenteric pouches to the nerve cord, notochord, and digestive tract. *e*, Ectoderm; *c*, coelom; *d*, digestive tract; *nc*, nerve cord; *n*, notochord.

C, Still later stage. The mesoderm has divided into blocks, called somites, each one of which has three regions: epimere (*em*), mesomere (*mm*), and hypomere (*hm*). The epimere gives rise to muscle tissue (*m*) and contributes to the skeletal structures (*sk*). The mesomere also contributes to the skeletal tissue, and forms the gonads and excretory organs. The hypomere forms the coelomic walls which are seen approaching on the dorsal and ventral sides to form mesenteries. The forebrain (*fb*), midbrain (*mb*), and hindbrain (*hb*) have been differentiated at the anterior end. (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

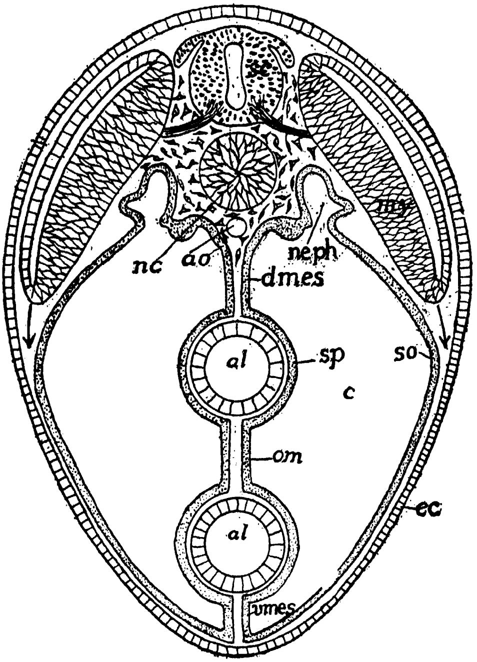


Fig. 295.—Diagrammatic cross-section of a vertebrate to show the general relation of the organs, and the formation of mesenteries about the alimentary canal (*al*) ; *dmes*, dorsal mesentery ; *vmes*, ventral mesentery ; *om* omentum ; *c*, coelom ; *so*, somatic, and *sp*, splanchnic wall of coelom ; *sc*, spinal cord ; *nc*, notochord ; *ao*, aorta ; *ec*, ectoderm ; *my*, myotome (muscle tissue pushing in between the ectoderm and the coelomic wall). The loose tissue about the notochord is mesenchyme which will form the vertebrae. (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

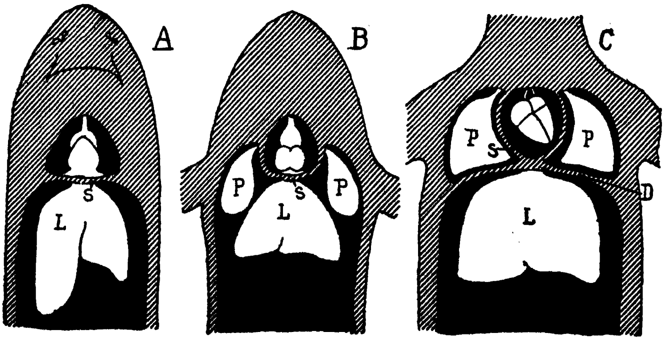


Fig. 296.—Diagrams showing the divisions of the coelomic cavities in solid black: in *A*, fishes ; *B*, amphibians, reptiles, and birds ; and *C*, mammals. *L*, Liver ; *P*, lungs ; *S*, transverse septum ; *D*, diaphragm. (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

they are completely covered by layers of the peritoneum. On the dorsal side, the mesentery is retained in most of the vertebrates, but the ventral mesentery breaks. The kidneys are outside the coelomic wall, and are, therefore, considered to be retroperitoneal.

In fishes, amphibians, reptiles and birds a *transverse septum* separates an anterior pericardial cavity from a posterior *pleuroperitoneal* cavity in which all other viscera are slung. In the higher amphibians and in the reptiles and birds the pericardial cavity has moved to a ventral position, so that the transverse septum is oblique instead of transverse. In birds a fibrous tissue from the peritoneum covers the ventral surfaces of the lungs, forming a partial partition. In mammals a muscular partition divides the cavity so that there is a thoracic and an abdominal cavity. This partition is known as the *diaphragm.*

Skin

The skin consists of two layers: an outer layer of ectoderm cells, *the epidermis,* and an inner layer of mesoderm cells, the *dermis.* The skin contains sensory cells, pigment cells, and excretory glands, such as the simple mucous glands of fishes, and the complex oil, sweat, and mammary glands of higher forms. Often such outgrowths as scales, teeth, feathers, hair, nails, claws, and hoofs appear. These constitute the exoskeleton, and are protective.

Endoskeleton

The endoskeleton differs from all other skeletal structures in animals in being made of living cells which grow and expand with the growth of the organism. This fact alone accounts for the great size attained by the vertebrates.

The skeleton is preceded in formation by the notochord which is more or less completely replaced by cartilage during development. The cartilage again is more or less completely replaced by bony tissue, which is designated as *cartilage,* or *replacing* bone. To it is added bone tissue which is laid down in the skin and is not preceded by cartilage. This is known as *dermal, membrane,* or *investing* bone.

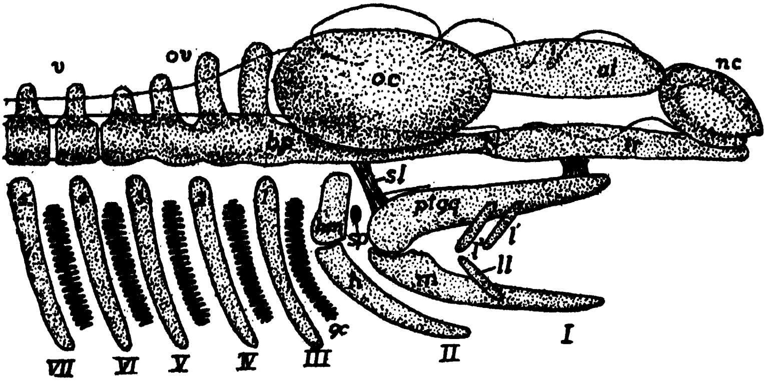


Fig. 297.—Diagram of the skull and visceral arches of an elasmobranch fish in which the cartilage is not replaced by bone. The primitive skull consists of the nasal capsule (*nc*); the otic capsule (*oc*); the basal plate (*bp*); the trabeculae (*tr*); the alisphenoid plate (*al*), and the first two visceral arches which form the jaws and their support. The pterygoquadrate (*ptgq*) forms the upper jaw, and the Meckel's cartilage (*m*) the lower jaw. The hyomandibular (*hm*), and the hyoid (*h*) support the jaw, and the branchial arches (1-5) support the gills (*gc*). The first gill slit, the spiracle (*sp*) forms the eustachian tube in terrestrial vertebrates, and the cartilaginous jaws are replaced by bone; *I-VII*, visceral arches; *v*, vertebrae; *ov*, occipital vertebrae; *sl*, suspensory ligaments; *l*, *ll*, labials. (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

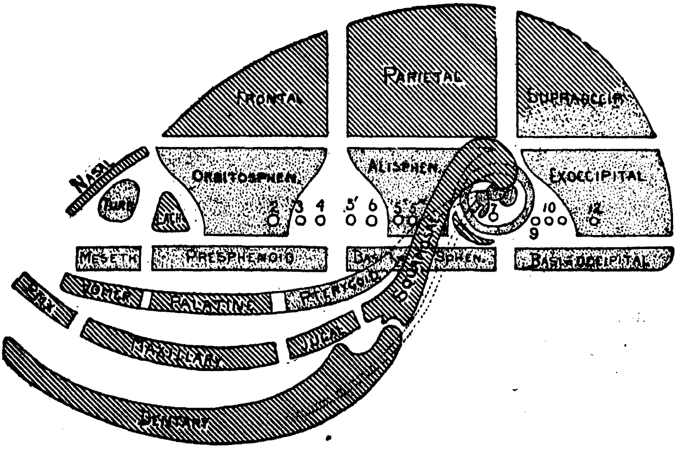


Fig. 298.—Diagram of the bones of the mammalian skull. Cartilage bones dotted; membrane bones lined; 1-12, exits of cranial nerves. (After Flower.) (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

There is a tendency in the higher vertebrates for originally separate bones to fuse, and in some cases to drop out entirely, so that the number of bones in the mammalian skeleton is much less than in the lower groups. All bones not in the midline are paired. The lines of fusion between separate bones are known as sutures.

The endoskeleton consists of two parts: an *axial* skeleton including the skull and backbone and an *appendicular* skeleton which supports the appendages. The skull consists of a *cranium,* or brain case, and a *visceral* skeleton which supports the gills in fishes and contributes to the bones of the face and ear. The vertebrae form a supporting axis, but are movable on each other so that the axis is flexible. The ribs support the trunk and are movable. True ribs are united ventrally by a *sternum,* or breastbone. If not so attached, they are called false ribs. The fore limbs are attached to the *pectoral* girdle and the hind limbs to the *pelvic* girdle. Originally each girdle is made up of three cartilage bones which meet at the point of articulation with the limb. The fore limb articulates in a depression, the *glenoid fossa;* the hind limb, in the *acetabulum.*

Muscles

Motion in vertebrates is accomplished by muscular contractions. The muscles are of two kinds:

1. The *striated,* voluntary muscles, attached to the skeleton—move one part on another.
2. The *smooth,* involuntary muscles, frequently circular—supply the internal organs.

Muscles are usually attached by one or both ends to bones. Attachment may be direct, or by means of an inelastic band of connective tissue, a *tendon.*

The origin of the muscle is the end attached to a relatively immovable bone.

The insertion is the end attached to a movable bone.

Because of the origin and insertion, muscles move one skeletal part on another, the type of action depending upon the origin and insertion.

Flexor—bends one part on another.
Extensor—extends a part.
Adductor—draws a part toward the midventral line.
Abductor—pulls a part away from the midventral line.
Depressor—lowers a part.
Levator—raises a part.
Rotator—rotates one part on another.

Nervous System

The nervous system is well developed and cephalization has advanced even in the lowest vertebrates to a well-defined brain. Intelligence increases gradually throughout the group.

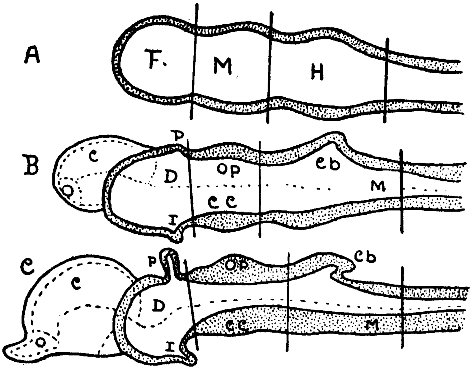


Fig. 299.—Diagrams to illustrate the development of the vertebrate brain. *A*, Stage of first differentiation. *B*, Intermediate stage. *C*, Stage of complete differentiation. *F*, Forebrain; *M*, midbrain; *H*, hindbrain; *O*, olfactory region; *C*, cerebral region; *D*, diencephalon; *P*, pineal body; *I*, infundibulum; *OP*, region of optic lobes; *CC*, region of crura cerebri; *CB*, cerebellum; *M*, medulla. (Modified from Kingsley.)

The unit of the nervous system is the *neuron* which is a cell with a nucleus and with *axones* and *dendrites* extending from the body of the cell in opposite directions. They appear either grey or white according as the nerve tissue is surrounded by an insulating sheath of white, nonnervous tissue. Where several cells are grouped together a ganglion is formed. Several axones in a single sheath form a nerve.

Stimuli enter the neurons through the dendrites and leave through the axones which may extend the entire length of the body. Neurons do not come in contact with other neurons, the stimulus passing from the axone of one to the dendrite of another, much as a spark of electricity passes from wire to wire. They are directive cells, stimuli passing in one direction only, and so are either afferent or efferent according as they carry stimuli to or from the central nerve cord.

There are three divisions of the nervous system: the *central,* including brain and nerve cord; the *peripheral,* including cranial and spinal nerves; and the *autonomic* system which supplies the internal organs.

Central Nervous System

Anterior to the notochord the nerve cord enlarges into three lobes: the *fore-, mid-,* and *hindbrain.* These in turn develop into the adult brain structures as follows:

Forebrain	Olfactory lobes. Cerebral hemispheres. Diencephalon—Infundibulum, a growth from the floor contributes nervous portion to pituitary gland. Pineal body, a growth from the roof becomes the pineal gland which is typically separated from the brain in the adult.
Midbrain	Optic lobes form from roof. Crura cerebri form from floor.
Hindbrain	Cerebellum—over roof of fourth ventricle. Medulla.

Peripheral Nervous System

Cranial and *peripheral* nerves arise in pairs from the nerve cord. The spinal nerves have typically two roots: a sensory, or *afferent,* and a motor, or *efferent.* The cranial nerves do not have two roots and may be either motor, sensory, or mixed in function. One motor and one sensory cranial nerve represents one segment in origin, as does each pair of spinal nerves. Cranial nerves are either ten or twelve in number, according to the number of segments included in the head region.

Autonomic Nervous System

A chain of ganglia on either side of the spinal cord connects the central system with the digestive, circulatory, and endocrine systems. Afferent and efferent fibers connect these ganglia with all organs and with the central nervous system through the spinal nerves. These fibers are not subject to voluntary control, but are stimulated by changes in the internal environ-

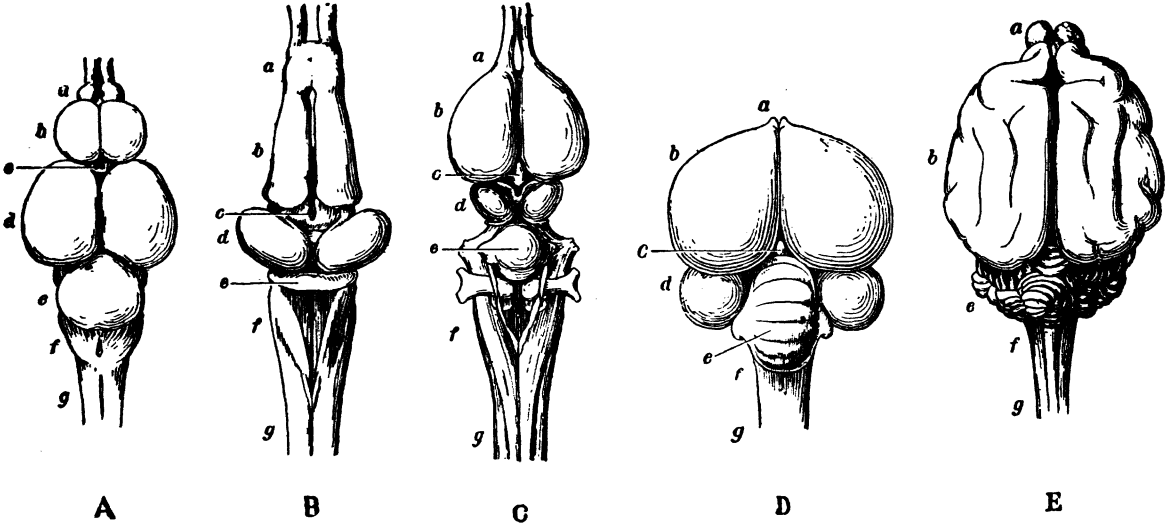


Fig. 300.—Dorsal view of the brain of: *A*, Bony fish (Perch); *B*, amphibian (frog); *C*, reptile (alligator); *D*, bird (pigeon); *E*, mammal (cat). *a*, Olfactory lobes; *b*, cerebral hemispheres; *c*, pineal body; *d*, optic lobes; *e*, cerebellum; *f*, medulla; *g*, spinal cord. (Reprinted by permission from Woodruff: Foundations of Biology. Published by The Macmillan Co.)

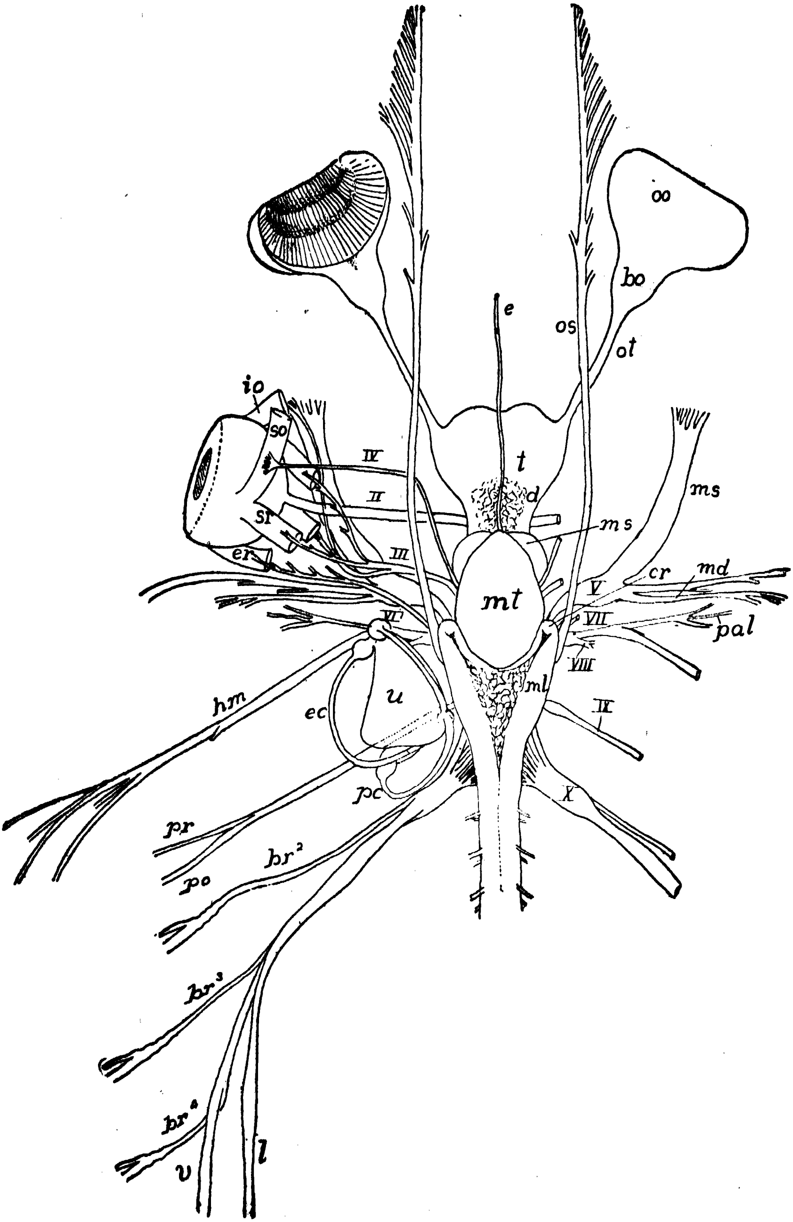


Fig. 301.

(See opposite page for legend.)

ment, and by such changes in the external environment as temperature change and stimuli which cause pain or emotional disturbance.

There are two sets of nerve paths with contrasting functions: the sympathetic, and the parasympathetic. All organs receive fibers from both sets.

Cranial Nerves

NO.	NAME	TYPE	ORIGIN	DESTINATION
I	Olfactory	Sensory	Olfactory lobe	Nostril
II	Optic	Sensory	Side of diencephalon	Retina of eye
III	Oculomotor	Motor	Ventral surface of crura cerebri	All eye muscles except superior oblique and external rectus
IV	Trochlear	Motor	Between optic lobe and cerebellum	Superior oblique eye muscle
V	Trigeminal	Mixed	Side of medulla	Ophthalmic branch to side of head, main branch to jaws
VI	Abducens	Motor	Ventral surface of medulla	External rectus eye muscle
VII	Facial	Mixed	Side of medulla	Palatine branch to orbit and floor of mouth; hyomandibular branch to muscles of hyoid and lower jaw
VIII	Auditory	Sensory	Side of medulla	Inner ear
IX	Glossopharyngeal	Mixed	Side of medulla	Branch joins hyomandibular to floor of mouth; branch joins vagus
X	Vagus (pneumogastric)	Mixed	Several roots from medulla	Larynx, heart, lung, stomach
XI	Spinal accessory	Motor	Medulla	Thoracic and abdominal viscera and muscles of pharynx and larynx
XII	Hypoglossal	Motor	Medulla	Muscles of tongue

Fig. 301.—Brain and cranial nerves of an elasmobranch fish, Carcharias. The cranial nerves are marked with Roman numerals except the first cranial which is the olfactory tract (*ot*) leading to the olfactory organ (*bo,* olfactory bulb; *oo,* olfactory capsule; *os,* superficial ophthalium). Brain: *t,* cerebral hemispheres; *d,* diencephalon; *e,* pineal body; *ms,* optic lobes; *mt,* cerebellum; *ml,* medulla. Eye muscles: *er,* external rectus; *sr.* superior rectus, *so,* superior oblique; *io,* inferior oblique. Ear: *ec,* external canal; *pc,* posterior canal; *u,* utriculus. Branches of cranial nerves: br^{1-4} branchial nerves; *v* and *l,* visceral and lateral branches of *X; po,* postrematic, and *pr,* pretrematic branch of *IX; hm,* and *pal,* hyomandibular and palatine branches of *VII; md* and *ms,* mandibular and maxillary branches of *V.* (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates, Published by P. Blakiston's Son & Co.)

Sympathetic.—When stimulated, the sympathetic fibers increase the heart rate, raise the blood pressure, arrest activity in the alimentary canal by contracting the arterioles there, and increase activity in the voluntary muscles by dilating the arterioles and by increasing the output of sugar from the liver to the blood. This increase in blood sugar concentration allows immediate recovery from fatigue and excessive muscular activity. On extreme stimulation the pupils of the eyes will dilate, the sweat glands secrete profusely, and the hair will become erected.

This is known as the emergency reaction, preparing the organism for unusual effort under stress. It is similar to the effect produced when the adrenal medulla is stimulated by the excessive secretion of adrenalin (see page 544).

Parasympathetic.—When stimulated the parasympathetic fibers slow the heartbeat, lower the blood pressure, and increase activity in the alimentary canal by dilating the arterioles there. In general, these are the activities of repose.

Neurohormones.—Secretions at the nerve endings that carry impulses across synapses and across myoneural junctions are called neurohormones. They have been identified at the endings of all autonomic nerves and some of the somatic nerves. Similar secretions have been identified in many invertebrates and in plants. It is a generally accepted idea today that the transmission of all impulses is accomplished by hormones and that chemical coordination and nervous coordination have been closely correlated from the simplest organisms to the highest.

The secretions at the endings of the parasympathetic nerves are the same as those found with the somatic nerves and have been identified as *acetylcholine.* The sympathetic nerves have a secretion similar to the secretion from the medulla of the adrenal gland. This is *adrenalin.* Reactions attributed to secretions from the medulla are the same as those brought about by stimulation of the sympathetic nerves.

Sense Organs

In even the lowest vertebrates the sense organs are well developed, though more diffusely distributed and less highly differentiated in the aquatic than in terrestrial forms, where the aerial environment presents a wider range of variation.

The ectoderm is the primary irritable tissue as it is the primary tissue of conduction. All sensory receptors are thus ectodermal in origin, but are at least partially sunk beneath the surface, the most superficial receptors having a mass of nonnervous tissue about them. The accessory tissues of the sense organs are mainly mesodermal, and the eye and ear are protected by bony tissue. The middle ear is lined with endodermal cells, however, because it represents the persistent canal of the first gill slit opening from the pharynx. Its function is the equalizing of pressure in the middle ear.

Receptors receive stimuli of one kind only, and are always in contact with nerve endings which transmit the stimuli to the central nervous system. Pressure on the eyeball or a blow on the head may irritate the eye, but the reaction will be a sensation of light even though no light waves are concerned.

Vertebrates are not all equally sensitive to stimuli even when closely related. Irritability to odor, for instance, is indifferently developed in man, but is very keen in lower mammals, while cats respond to higher tone waves, and ants to shorter light waves than man. The range of the human visible spectrum is between 481 billion ether waves per second, at the red end, and 764 billion at the violet end. The tonal range lies between 164 and 41,000 vibrations per second.

Reception of a stimulus is dependent upon a changing environment, so that the vertebrate organism, like the lower forms of life, shows a constant interaction between the internal and external environment.

Perception of a stimulus, however, involves judgment, since it is always referred back to the point of reception, and is not perceived in the brain. Intelligent choice of action plays an increasingly important part throughout the vertebrates, and together with individual variations in judgment, and the frequency of sensory illusions, makes the cataloguing of human reactions a difficult matter. Even when limbs are amputated, the individual refers sensations to the missing part, and often in the case of internal injury the pain is referred to some area of the skin.

Receptors of touch, pain, and thermal stimuli are found scattered over the skin, and there are certain internal receptors in the muscles and digestive organs. Otherwise, the receptors in land vertebrates are limited to special organs. Taste buds are limited to the tongue; receptors for odor to the lining membranes of the olfactory chambers in the nostrils; the receptors of light to the retina at the back of the eye; receptors of static stimuli to the semicircular canals of the inner ear; and receptors of auditory stimuli to the hair cells of the organ of Corti in the cochlea of the inner ear.

VERTEBRATE EAR

The auditory apparatus of the vertebrates has been a progressive development to which the gill slits and visceral arches of the fishes have contributed. The bones of the arches have pushed up into the lower jaw, and thence to the cheek, culminating finally in the middle chamber of the extremely sensitive mammalian ear. The first gill slit has persisted as a *eustachian tube* by which the middle ear communicates with the throat.

In the fishes, *lateral line organs* serve for the receipt of static stimuli and of wave currents which take the place of auditory stimuli in an aquatic environment. At the anterior end the lateral line organs open into an inner ear in which three *semicircular canals* develop at right angles to each other. These, also, have a static function.

In the Amphibia the eustachian tube opens into a middle ear chamber in which a rod of bone developed from the quadrate forms a *columella.* This transmits vibrations from a *tympanic membrane* stretched across its external opening to the inner ear.

In reptiles and birds a canal develops which is the beginning of the outer ear, and in the mammals the three-chambered ear is complete. The outer ear widens and curves into a conch which protects the tympanic membrane and concentrates and places vibrations. In the middle ear the columella has become the *incus,* the hyomandibular, the *stapes,* and the articulare from the lower jaw, the *malleus,* the three tiny bones along which vibrations are transmitted to the fenestra vestibuli through which they pass to the cochlea.

The Inner Ear.—The inner ear of mammals develops as an invagination from the ectoderm. This forms a membranous

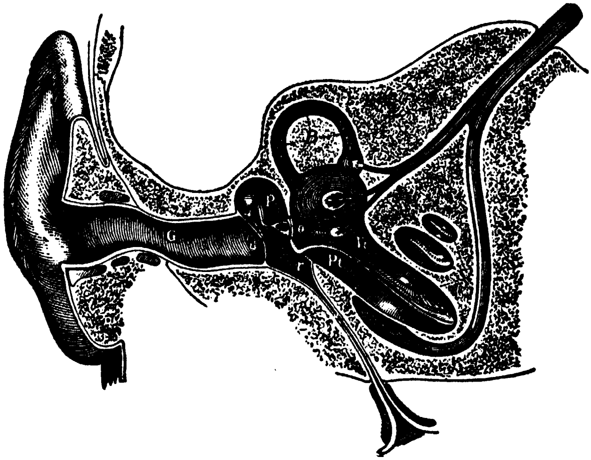


Fig. 302.—Diagram of the right ear (human). *G*, External auditory meatus; *T*, tympanic membrane; *P*, middle ear containing the three bones, malleus, incus, and stapes; *o*, oval window; *r*, round window; below *r*, is seen the opening of eustachian tube; *B*, semicircular canal; *S*, cochlea; *Vt*, scala vestibuli; *Pt*, scala tympani. (After Czermak.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

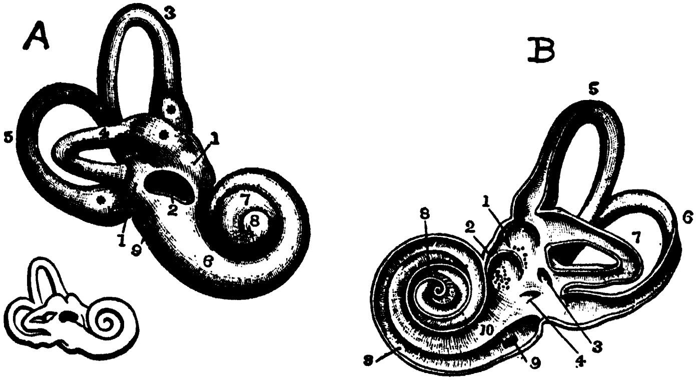


Fig. 303.—*A*, Right bony labyrinth of ear, outside. *1*, The vestibule; *2*, oval window; *3*, semicircular canal; *, ampullae of the semicircular canals; *4*, horizontal or external canal; *5*, posterior canal; *6*, the cochlea with *8*, the apex; *9*, round window. The small figure below shows the natural size. *B*, Left labyrinth, interior. *1*, *2*, Interior of the vestibule; *3*, common opening of the superior and posterior semicircular canals; *4*, opening of the aqueduct of the vestibule; *5*, the superior, *6*, the posterior, and *7*, the horizontal semicircular canals; *8*, the cochlea (scala tympani); *9*, opening of the aqueduct of the cochlea; *10*, placed on the lamina spiralis in the scala vestibuli. (After Sömmerling.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

chamber which pinches into two parts: a *utriculus,* in which the *semicircular canals* develop, and a *sacculus,* in which the *cochlea* is formed. The membranous labyrinth is surrounded by a bony labyrinth sculptured out of the temporal bone. The spongy bone tissue surrounding the inner ear is the mastoid tissue.

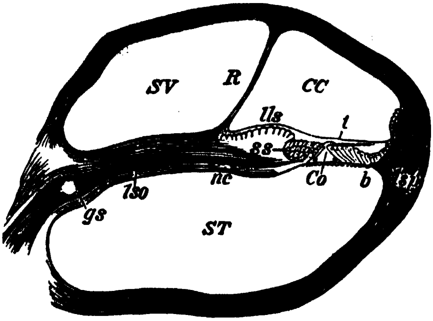


Fig. 304.—Section through one of the coils of the cochlea. *ST,* Scala tympani; *SV,* scala vestibuli; *CC,* canalis cochlea; *R,* Reissner's membrane; *lso,* lamina spiralis ossea; *nc,* cochlear nerve; *b,* basilar membrane; *Co,* rods of Corti. (After Henle.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

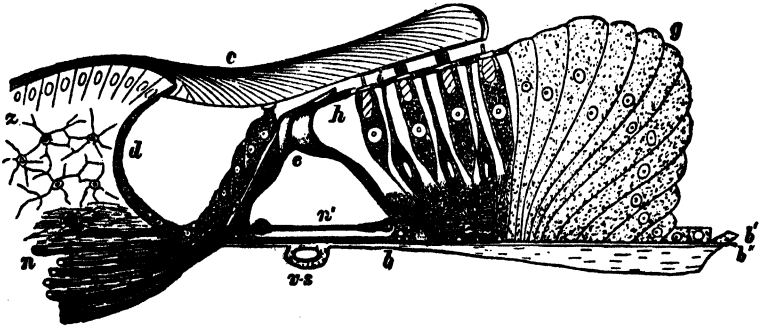


Fig. 305.—The organ of Corti. *b,* Basilar membrane; *e,* Corti's arch; *g,* supporting cells; *h,* cylindrical cells; *i,* Deiter's hair cells; *c,* tectorial membrane; *n, n',* nerve fibers. (After Munk.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

In the bony chamber is a liquid *perilymph,* and in the membranous chamber is an *endolymph.*

The Utriculus.—The three semicircular canals contain endolymph, and are lined by hairs on which minute floating *otoliths* rest. The angle of the hairs and the pressure of the otoliths determine the sensation of equilibrium. These hairs are known as *static receptors.*

The Sacculus.—The coiled *cochlea* is an elongation of one end of the utriculus. A *basilar membrane* divides the perilymphatic space into two chambers, the *scala tympani* below, and the *scala vestibuli* above.

Upon the basilar membrane rests the membranous labyrinth of the cochlea which is filled with endolymph. The cavity is called the *scala media*, and is separated from the perilymphatic cavity by a thin membrane known as *Reissner's membrane.* A bony *lamina spiralis* forms a minute shelf extending into the cavity.

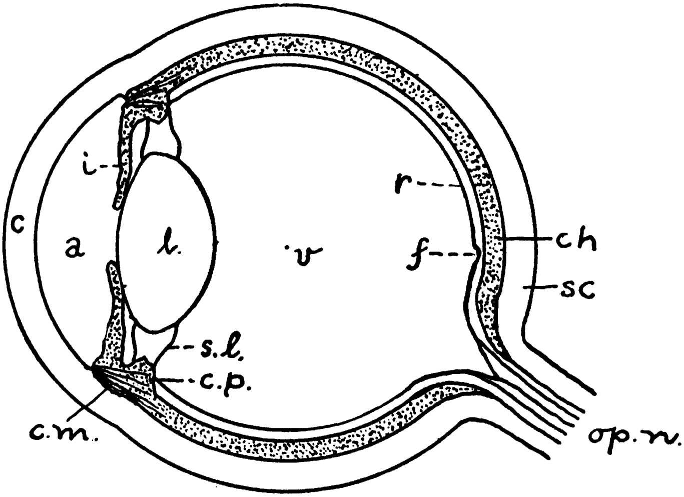


Fig. 306.—Diagram of the eyeball. *c*, Cornea; *a*, aqueous humour; *l*, lens; *v*, vitreous humour; *sc*, sclerotic coat; *ch*, choroid coat; *r*, retina; *f*, fovea centralis; *op.n.*, optic nerve; *c.m.*, ciliary muscles; *c.p.*, ciliary body; *s.l.*, suspensory ligament. (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

Inside the scala media, and lying across the basilar membrane, are the *hair cells* in five rows. These are the auditory receptors which communicate along the lamina spiralis with the endings of the auditory nerve. The hair cells form two spiral bands throughout the cochlea, increasing in size toward the tip, thus providing for perception of a range of tones. Extending over the hair cells from the lamina spiralis is a *tectorial membrane* which presses lightly on the hair cells, thus acting as a damper on the vibrations.

VERTEBRATE EYE

The vertebrate eye is not only a light-perceiving, but an image-forming organ. The optic cup, which is the sensitive portion, is budded off from the forebrain, and the lens is invaginated from the skin, so that both are ectodermal in origin. The eyeball has two outer coats of mesoderm and the whole is enclosed in a bony socket in the skull. The structure is complete in fishes and varies only in detail within the groups.

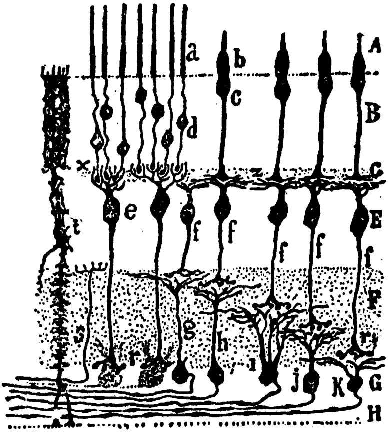


Fig. 307.—Diagram showing the three neural layers of the retina. *A, B, C,* The outer layer of rods, *a,* and cones, *b; E, F,* middle layer of bipolar cells; *G, H,* inner layer of ganglionated cells; *h,* optic nerve fibers; *t,* Müller's cells; the dotted horizontal line between *A* and *B* represents the external limiting membrane. (After Cajal.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

The Sclerotic Coat.—The outer layer is a tough, opaque white tissue, called the *sclerotic* coat. It maintains the shape of the eyeball and is visible in front as the "white of the eye." Across the front surface of the eye the tissue becomes transparent and is called the *cornea.* The six muscles which rotate the eyeball are attached to its surface.

The Choroid Layer.—A very vascular central layer containing pigment is called the *choroid* layer. At the front it becomes modified into a *ciliary ring* and an *iris.* The iris has a small hole, the *pupil* in the center, and contains circular and radial muscles which regulate the size of the pupil according to the amount of light entering the eye.

The ciliary ring is made up of *fibrous tissue,* the *ciliary processes,* and *ciliary muscles.* The ciliary processes contain blood vessels and form a point of attachment for the *suspensory ligament,* which supports the *lens.* The ciliary muscles control the shape of the lens, bringing objects to focus on the retina, and accommodating the eye to near and far vision.

The pigment of the choroid layer gives the characteristic color to the eye. It is most abundant in the iris where it is distributed in two layers. A purple black pigment lies back of the iris. Light refracted from this layer gives the blue color to the eye. When brown pigments are present they lie in front of the iris and conceal the blue. This is called *epistasis.* Brown pigments vary in amount giving the familiar range in shade to the brown eye.

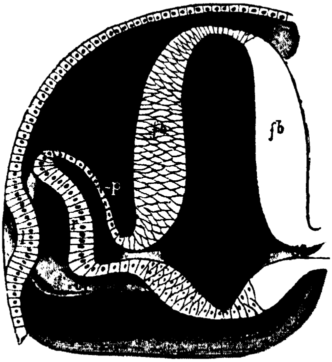


Fig. 308.—Stereogram of developing eye, to show relation of eye to forebrain (*fb*), and the invagination of the ectoderm to form the lens (*l*); *cf,* chorioid fissure; *oc,* optic cup; *os,* optic stalk; *p,* pigmented layer; *r,* retinal layer. (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

The Retina.—The retina is a double layer on the inner surface of the eyeball, and is the original optic cup. Its outer layer is pigmented, and the inner layer contains the *rods and cones.* Cones are cells used in the detection of color, and rods in the detection of light and motion. The rods secrete a pigment, called the *visual purple,* which is supposed to assist in some unknown way in the detection of brightness. (See under Vitamin A in Chapter XII for function of carotene in maintaining a normal amount of visual purple in the eye.)

The rods and cones are the light receptors which communicate with the optic nerve through two layers of cells, a layer of intermediate and a layer of ganglionated cells, the latter connecting directly with the optic nerve.

The retinal layer is the only layer which is not continued across the front of the eye. It terminates just back of the ciliary ring in an irregular circle. Although the sensitive cells continue around the greater part of the eyeball, only a small area is capable of clear vision. This portion, the *macula lutea,* is yellowish in color, and in its center is a conical depression, the *fovea centralis,* where a few rods and many cones are accumulated. This is the region of sharpest focus.

The Lens.—Focussing of the image is accomplished by the lens. This is a transparent, cellular structure which develops by an invagination of skin cells. It is suspended from the ciliary ring by the suspensory ligament.

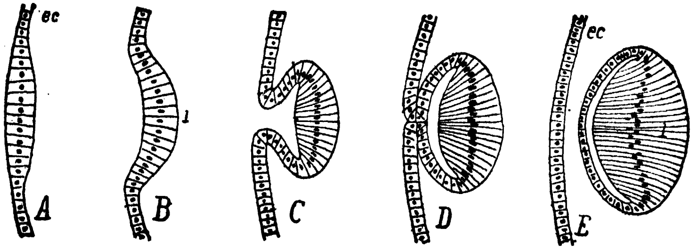


Fig. 309.—Sections of successive stages in the development of the lens of the vertebrate eye from the first thickening of the ectoderm (*ec*) to the complete separation of the lens (*l*). (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

The posterior face is more curved and less subject to change than the anterior face which is modified by the pull of the ciliary muscles. Rays of light entering the eye are refracted in the lens so that they will come to a focus on the retina. Rays not so focussing will give a blurred vision. If they come to a focus in front of the retina, the eye is said to be nearsighted; if in back, farsighted. In either case the defect can be remedied by the use of additional lenses to change the amount of refraction.

The lens rests in a depression in the *vitreous body* which is a semigelatinous transparent mass filling the center of the eyeball. The space in front of the lens is filled with a more liquid *aqueous humour.*

Digestive and Respiratory Systems

The digestive system varies in detail among the vertebrates, but the general plan is similar in all. Except in the prochordates and cyclostomes, there are *jaws,* and the *buccal cavity* bears *teeth.* The movable lower jaw assists in the seizure and mastication of food. Usually *salivary glands* are found in the walls of the mouth region.

Gill slits in the wall of the *pharynx,* or throat region, open to the outside in all vertebrate embryos. These persist as gills in adult fishes and in some amphibians. In all other forms the gill slits close and a *trachea* develops as an outgrowth from the midventral line of the pharynx from which two sacs branch off to become the lungs. These replace the gills in air-breathing types.

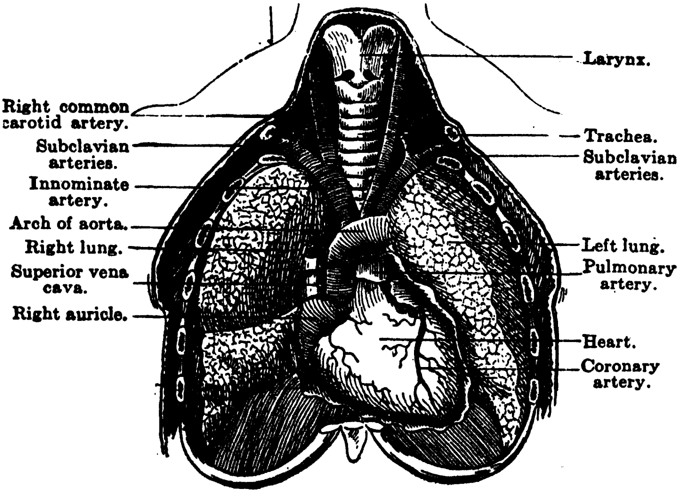


Fig. 310.—Thoracic cavity of mammal. (After Ingals.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

The *esophagus* is a narrow tube leading from the pharynx to the stomach. Its length varies with the length of the neck. In birds it becomes enlarged at its posterior end into a *crop.*

The *stomach* is a modification of the vertebrate digestive tract which makes possible periodic, instead of continuous feeding, by its generous storage facilities. Its function is threefold: storage, muscular churning of the food, and glandular secretion for digestion. It is frequently modified into regions for the separate functions, as in the bird in which the cardiac end becomes a gizzard, and in the ruminants (cows, etc.) in which four separate stomachs are formed, each with an individual function. The *cardiac* end is wide, and admits food from the esophagus. The *pyloric end* is narrower and is controlled by a circular muscle, the *pyloric sphincter,* which relaxes only on definite stimulus to admit food to the intestine. Usually the stomach lies in a transverse position, the pyloric end bending forward, a modification favoring the retention of food.

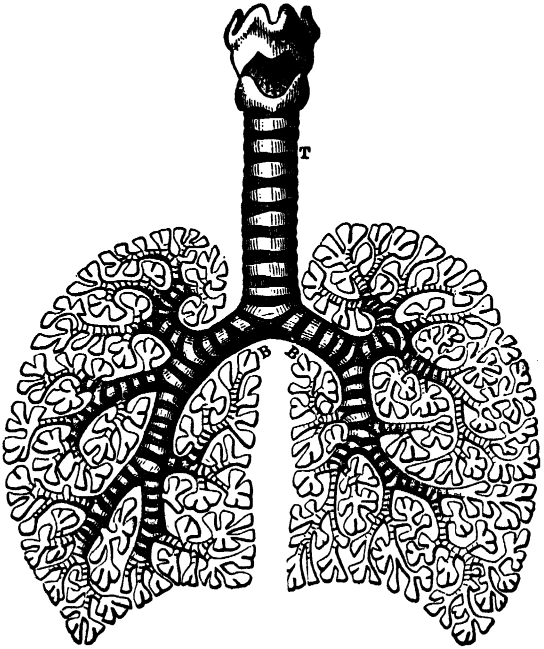


Fig. 311.—Mammalian respiratory tract. *T,* Trachea with larynx; *B,* bronchi. (After Dalton.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

The intestine is the main portion of the digestive tract. Here digestion is completed; absorption of the digestive products into blood and lymph vessels for distribution to the tissues is accomplished and undigested portions are finally prepared for egestion. Absorption through the intestinal walls is a process of living cells and osmosis plays a relatively unimportant part.

The presence of sterols in the cell wall is believed to aid in carrying food products through.

There is a progressive tendency to increase both the time and the surface for absorption. The intestine becomes lengthened by coiling, often being several times the length of the body; the surface is further increased in aquatic forms by such infolding as *typhlosoles* and *spiral valves,* and in terrestrial forms by papilla-like projections with extraordinary absorptive powers, culminating in the *villi* of the mammalian intestine.

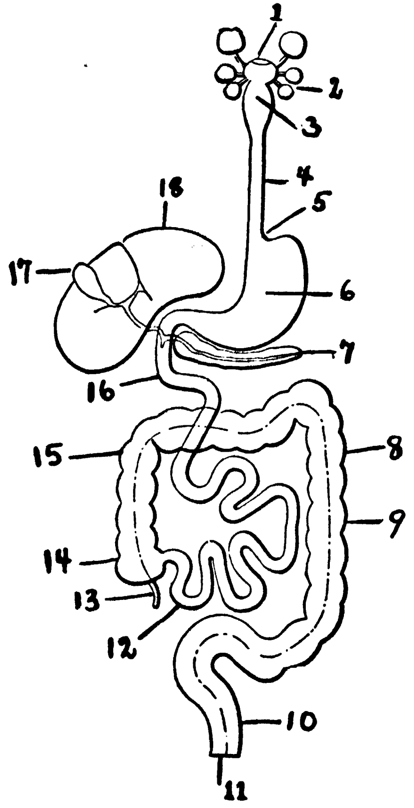


Fig. 312.—Diagram of the human digestive tract and its appendages. *1,* mouth; *2,* salivary glands; *3,* pharynx; *4,* esophagus; *5,* cardia; *6,* stomach; *7,* pancreas; *8,* descending colon; *9,* large intestine; *10,* rectum; *11,* anus; *12,* small intestine; *13,* appendix; *14,* caecum; *15,* ascending colon; *16,* duodenum; *17,* gallbladder; *18,* liver. (After Testut.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

In all groups above the fishes the posterior end becomes differentiated into a large intestine in which undigested food materials are softened by fermentation, and prepared into feces for egestion. In all except the mammals, the excretory ducts of all internal organs open into a common cloacal chamber so that there is a single external aperture, the anus.

The *liver* is the largest gland. It develops from the wall of the intestine and is permanently attached to it by means of a common duct which receives both the bile duct and the hepatic duct. It enters the intestine in the first bend posterior to the stomach, known as the *duodenum*. Frequently there is a gall bladder for the storage of excess bile.

The function of the liver is multiple.

1. The liver serves as a temporary *storage* organ for excess carbohydrate food. This is stored in the form of *glycogen,* or animal starch. It can be converted back into soluble form on demand.

2. It serves as an excretory organ, forming urea from the amino acids of protein digestion. This is later conveyed to the kidneys through the blood stream.

3. A further function is that of collecting and excreting broken down corpuscles, in the form of bile pigments. These may be either yellow or green according to the diet of the organism, herbivorous animals secreting more of the yellow pigment. Liver tissues may also contribute to the formation of the red blood corpuscles, especially in the embryos.

4. Another function of the liver is the secretion of *bile*. Bile is an alkaline liquid which aids in digestion and absorption, and serves as a channel of excretion for many waste products of metabolism. The color of bile is due to the *bile pigments.* Prominent among the waste products found in the secretion is *cholesterin* which is formed from broken down nerve tissue, and which may crystallize in the tissues to form gallstones.

The *bile salts* are both organic and inorganic. They include the salts of the *bile acids* which contribute to the digestion and absorption of fats without being in themselves digestive, and which serve to keep cholesterin in solution.

The *pancreas* is a compound gland, lying in the duodenal fold. A pancreatic juice containing enzymes for fat, protein, and starch digestion, enters the digestive tract through a pancreatic duct. An internal secretion, insulin, from the *islands of Langerhans* contributes directly to the blood stream and aids in the oxidation of sugars.

Endocrine System

The glands of internal secretion are developed from various tissues, and belong, anatomically, to various systems, but, because of their interrelation in accomplishing their common function of chemical coordination, they may be considered as constituting an endocrine system.

The **pituitary gland** has a double origin. The anterior lobe develops from non-nervous cells of the mouth region; the posterior lobe, from a portion of the floor of the diencephalon of the forebrain. Both portions become glandular. They are enclosed within a bony pocket, the *sella turcica.*

Each lobe is known to have several distinct principles within the secretions, each one of which has a specific effect on some organ or on some activity. Certain of these principles control the secretions of other endocrine glands, and the pituitary is, therefore, looked upon as the master gland, dominating the entire endocrine system.

The effects of some of the known principles in the secretions of the anterior lobe are as follows:

1. *Control of Skeletal Growth.*—If the sella turcica is ossified at birth, preventing expansion of the gland, the dwarfs which result have small arms and legs and retarded mentality.

If the deficiency occurs during early development, growth may be retarded at any age. The resulting dwarfs have normal proportions.

An excess during childhood or adolescence causes gigantism.

An excess in adult life after skeletal growth has been completed causes acromegaly, a disease in which the face, hands, and feet become enlarged.

2. *Control of Thyroid Activity.*—The amount of activity in the anterior lobe determines the amount of activity in the thyroid. The effect on the organs is the result of thyroid secretion, not pituitary. Therefore, the effect of the anterior lobe secretion is on the thyroid itself.

3. *Control of Parathyroid Activity.*—Normal development of the parathyroid gland depends upon a healthy pituitary.

4. *Control of the Adrenal Cortex.*—Atrophy of the adrenal cortex can be restored to normal by injections of anterior pituitary.

5. *Control of Sugar Metabolism.*—An increase in pituitary secretion will cause disturbances in the metabolism of sugars, similar to those found in diabetes. Destruction of the islands of Langerhans in the pancreas has the same effect, but in an animal from which the pituitary has been removed, removal of the pancreas is not followed by diabetic symptoms. The presence of the pancreas secretions, therefore, is normally inhibiting to the action of the pituitary secretion.

6. *Control of Gonad Activity.*—All secretions and activities of the gonads cease in the absence of the pituitary secretions. The relative amount of activity, therefore, is determined by the amount of pituitary secretion. Many of the activities of sex normally connected with the sex organs are, in reality, determined by the pituitary gland.

7. *Control of Milk Secretion From the Mammary Glands of Females.*—This is a process usually connected with gonad activity, but the principle which controls it is not the same as the one that controls other gonad actions.

8. *Control of Fat Metabolism.*—In conjunction with the posterior lobe, a principle in the anterior lobe controls normal fat metabolism. Deficiency in adolescence causes weights from 300 to 400 pounds. The fat ladies of the circus are of this type of obesity. Deficiency following some childhood diseases causes obesity characterized by a voracious appetite, an abnormal craving for sweets, and a somnolent attitude.

Secretions of the posterior lobe are less well defined. They are believed to control blood pressure, the degree of contractility of smooth muscles, and the activities of the kidneys related to the volume of output of urine.

The **pineal gland** develops from the anterior portion of the epiphysis which is an outgrowth from the roof of the diencephalon, and later becomes separated from the brain.

The gland reaches its maximum at about the seventh year, after which its glandular structure begins to diminish. It is probable that the secretions are regulating during childhood, inhibiting premature development. Very little experimental evidence of this is available, but in certain cases of premature sexual development there has been found a tumor in the pineal gland.

The thymus, thyroid, and parathyroid glands are developed from the pharynx region of the digestive tract from the tissues of the gill pouches. In the duodenal region the digestive tract also produces the pancreas.

Thymus.—The rating of the thymus gland as an endocrine is somewhat in doubt. It is most prominent at birth and decreases gradually until puberty, when it usually disappears. In some cases, it persists throughout life. Some relation to growth is indicated.

Thyroid.—The secretions of the thyroid are extremely important, since they control the rate at which sugars can be oxidized; in other words, the rate of basal metabolism. Since the rate of oxidation affects all tissues, the regulating action of the thyroid is seen in other glands. This is especially marked in the activities of the reproductive organs.

A person with a high metabolic rate will burn sugars rapidly, and remain continuously thin, whereas a person with a low rate may accumulate fat regardless of the diet. These conditions will influence all activities. They may change after adult growth has been attained, and the tendencies of puberty may be reversed. The changes in thyroid activity are coincident with changes in sexual activity, which are sometimes referred to as "the tides of life."

Parathyroid.—The parathyroid glands are small bodies embedded in the tissue of the thyroids. Their secretions control the calcium concentration in the blood.

The irritability of tissues depends upon the relative concentration of sodium, potassium, and calcium in the blood. Any increase in sodium or potassium, or any decrease in calcium, will make the tissues more irritable.

Pancreas.—The internal secretion from the islands of Langerhans in the pancreas is known as *insulin.* In its absence, the body cannot utilize sugars for oxidation and has to get its energy from fats and proteins. The disease is known as diabetes, and the discovery of a method of extracting insulin from the pancreas of animals has been a great boon to those suffering from this disease. All symptoms of the disease may disappear, following the judicious use of insulin, but the sugar tolerance of each individual must be determined to establish the proper dose. The injected insulin alters in some way the character of the blood sugars, so as to render them available for consumption by the tissues.

The **adrenal glands** are double in origin, the central medulla developing from the same tissues as do the sympathetic nerves, and the outer cortex from coelomic epithelium. In the lower vertebrates the two tissues are not united into a single organ.

The medulla secretes *adrenalin,* long known as the emergency hormone. As would be suspected by the origin of the medulla tissue, this secretion is identical with that of the sympathetic nerve endings of the autonomic system. The effect of the secretion is identical also. The heart is invigorated, blood pressure is raised, blood sugar concentration is increased, arterioles of the cutaneous regions and of the alimentary canal are constricted, those of voluntary muscles are dilated, and, in extreme cases, the pupils of the eyes are dilated, sweat glands secrete profusely, and the hair tends to be erected.

Adrenalin can be used in cases of hemorrhage to strengthen the heartbeat and constrict surface arterioles.

Secretions of the cortex are much less well known. There is some evidence to show that they control the volume of liquid within the blood vessels. Removal of the cortex causes liquids to pass out of the vessels into the tissues, causing a rapid fall in blood pressure and death.

The **gonads** of vertebrates have internal secretions in addition to their reproductive functions, and so contribute to the endocrine system.

These secretions are produced only in the presence of secretions from the anterior lobe of the pituitary. Those of the female in mammals are subject to cyclic change and to periodic readjustment; those of the male are not.

One of the outstanding effects of gonad secretions is the development of the secondary sexual characters by which the sexes may be distinguished. These include the plumage of the male bird, the horns of deer and cattle, and the hair on the face of man.

The influence of secretions on these characters in mammals is the reverse of that in birds. Removal of the ovary in birds at any age is followed by development of male plumage; in mammals, no male characters appear. Removal of the testes in birds results in an infantile plumage, but not a female one; in mammals, if done early enough, the male tends to be feminized.

Circulatory System

The vascular system of vertebrates is closed. There is always a *heart* which lies in a ventral position and has at least two chambers: a muscular *ventricle,* which pumps the blood forcibly into the *arteries,* and a thin-walled *auricle,* which receives the blood from the *veins.* The heart is enclosed in a division of the coelom called the *pericardial cavity.* It is lined with a membrane, the *pericardium.*

The arteries are subdivided repeatedly so that the diameter of the vessels which reach the tissues is very small. The minute arteries just before subdivision into *capillaries* are called *arterioles.* They are capable of constriction and dilation when stimulated by the fibers of the autonomic nervous system, and so control the amount of flow into the capillaries. The capillaries are the final subdivisions. They have very thin walls through which the exchange takes place between oxygen and carbon dioxide, and between the end products of digestion and the end products of metabolism. White blood corpuscles may also pass through the capillary walls. The red blood corpuscles, however, pass directly through the capillaries of the arteries into the capillaries of the veins.

The blood of all vertebrates contains *red blood corpuscles,* which derive their color from a substance known as hemoglobin. This substance has a peculiar affinity for oxygen, and so has an accessory respiratory function in transporting oxygen to the tissues. When present in invertebrates hemoglobin is always in solution in the plasma. Except in mammals, the red blood corpuscles are nucleated. In mammals they lose their nuclei during development.

White blood corpuscles are present in both the blood and the lymph. These function as scavengers, and pass by amoeboid movements through the capillary walls. The substratum of the blood is a colorless plasma. It not only contains salts in solution, thus maintaining the osmotic pressure of the organism, but also the many substances required in clotting of the blood, in acquiring immunity to disease, etc. In addition, the blood acts as a carrier for carbon dioxide and all substances which must be conveyed to or from the tissues.

The *lymph* is similar to the blood without the red blood corpuscles. It bathes all tissues, and flows through the vessels of the lymphatic system.

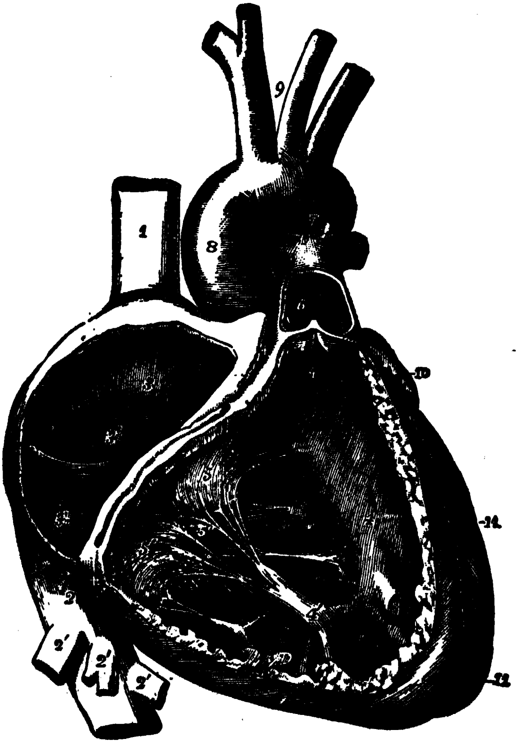


Fig. 313.—Mammalian heart. Right auricle and ventricle opened. *1*, Anterior vena cava; *2*, posterior vena cava; *2'*, hepatic veins; *3*, right auricle; *3"*, close to aperture of coronary vein; +, +, in the auriculoventricular groove; *4*, *4*, cavity of right ventricle, the upper figure immediately below the semilunar valves; *4'*, large papillary muscle *5*, *5'*, *5"*, the tricuspid (auriculoventricular) valves; *6*, pulmonary artery; *7* and *8*, arch of the aorta; *9*, between the innominate and left carotid arteries; *10*, outside of left auricle; *11*, outside of left ventricle; the lower figure near the apex. (After Thompson.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

A *portal system* is developed in connection with the liver of all vertebrates, and in some groups, with the kidney as well. A portal system is one in which veins open into capillaries within an organ, thus allowing a more effective exchange of materials. Since all of the blood in the body must pass through the liver, and because of the multiple function of the liver, this exchange is of primary importance, relieving the blood of many excess materials.

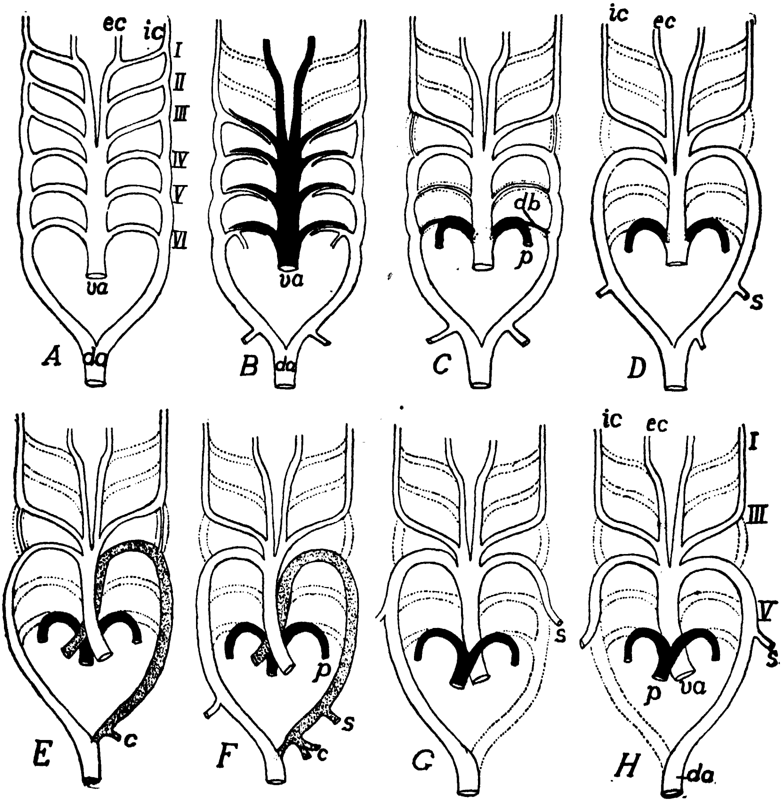


Fig. 314.—Diagrams showing the modifications of the aortic arches in different vertebrates. *A*, Primitive scheme; *B*, lungfish; *C*, primitive amphibian: *D*, frog; *E*, snake; *F*, lizard; *G*, bird; *H*, mammal. *ec*, *ic*, External and internal carotids; *va*, ventral aorta; *da*, dorsal aorta; *db*, ductus Botalli; *p*, pulmonary artery; *s*, subclavian; *c*, celiac artery. Vessels carrying venous blood black; those with mixed blood, shaded; those which disappear, dotted outlines. (After Boas.) (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

The double circulation of birds and mammals which accounts for their warm-blooded condition has been a progressive development, through the closing off of the heart chambers. In fishes the auricle and ventricle have one chamber each; in amphibians there is a partition through the auricle, but a single ventricle; and in the reptiles the partition is continued part way through the ventricle. In birds and mammals the four-chambered heart is complete (see Fig. 296).

This arrangement separates the flow of blood to the lungs from that to the systems, and valves prevent the backflow of blood from the ventricles to the auricles, and also from the arteries to the ventricle, so that a continuous flow is assured. The course of blood in the double circulation is as follows:

Systemic veins→ right auricle→ right ventricle→ pulmonary artery→ lung→ pulmonary vein→ left auricle→ left ventricle→ systemic arteries.

Excretory System

The excretory organs of vertebrates are kidneys which develop progressively throughout the groups to culminate in the compact, kidney-shaped organs of the reptiles, birds, and mammals. Characteristic of all are the kidney tubules with funnels, or *nephrostomes,* which collect salts from the lymph much as does the funnel of a nephridium in the annelids. The *glomerulus* is also a characteristic organ. This is a capillary network of arteries and veins which brings the blood into close contact with the tubules which secrete the urine for excretion. The arrangement in the lower forms is looser and shows the metameric derivation of the tubules better than does that in the higher forms. The number and concentration of glomeruli are related to problems of water conservation in the vertebrates (see Chapter XI).

The first kidney to form is called the *pronephros.* This consists of a long *segmental duct* with three tubules at the anterior end which develops on either side of the vertebrate embryo. It forms functional kidneys in the adults of a few fishes and in the embryos of fishes and amphibians.

A *mesonephros* replaces the embryonic pronephros in all vertebrates except the few fishes which retain the primitive type. The tubules grow off from the segmental duct posterior to the pronephric tubules. The funnels are better developed and the glomeruli are enclosed within them. The duct is retained and goes by the name of the wolffian duct. The tubules of the pro-

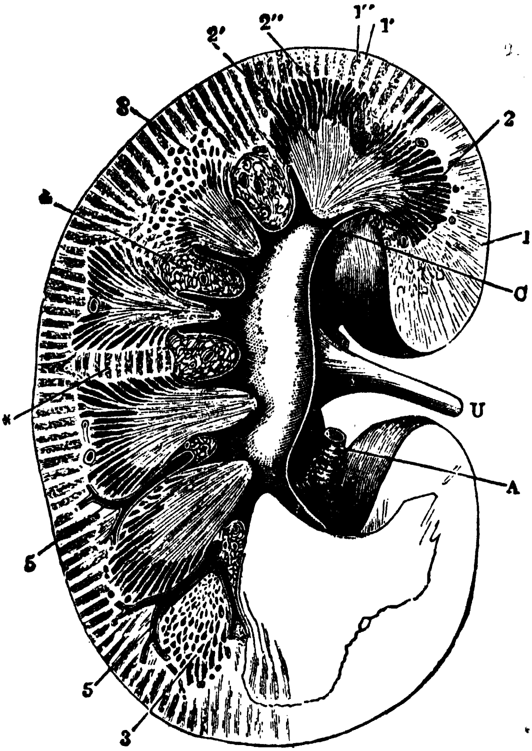


Fig. 315.—Section through a kidney. *A*, Renal artery; *U*, ureter; *C*, renal calyx; *1*, cortex; *1'*, medullary rays; *1''*, cortex proper; *2*, medulla; *2'*, papillary portion of medulla; *2''*, border layer of medulla; *3*, collecting tubules in section; *4*, fat tissue of the pyramids; *5*, branches of artery; *, medullary rays in cross-section. (After Henle.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

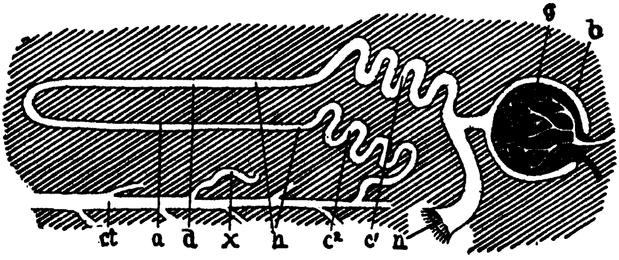


Fig. 316.—Diagram of a conventionalized excretory tubule. *a*, Ascending limb of Henle's loop; *b*, Bowman's capsule of malpighian body; C^1-C^2, first and second convoluted tubules; *ct*, collecting tubule; *d*, descending limb of Henle's loop; *n*, nephrostome opening into coelom; *x*, entrance of other tubules into collecting duct. (Reprinted by permission from Kingsley: Comparative Anatomy of Vertebrates. Published by P. Blakiston's Son & Co.)

nephros disappear. The mesonephros forms functional kidneys in the adults of most fishes and of all amphibians, and in the embryos of reptiles, birds, and mammals.

In the latter groups, the embryonic mesonephros is again replaced by a *metanephros* which is the compact, kidney-shaped organ, completely enclosing the capsules, so that no funnels open into the coelom. The metanephric duct is a *ureter.* It is formed as an outgrowth of the wolffian duct. In reptiles and birds the ureters from both sides join to form a single urethra before opening into the cloaca. Usually a bladder is formed from the wolffian duct. In mammals the ureters open directly into the bladder, the urethra having an external opening.

The wolffian duct is retained as a male reproductive duct, the female excretory duct developing separately from the mesoderm of the body wall.

Reproductive System

The Male Organs.—The gonads consist of a pair of testes connected by the tubular *vasa efferentia* with the wolffian duct which functions as a reproductive duct in all vertebrates having mesonephric kidneys in either embryo or adult. Where the mesonephros is the adult kidney, the duct serves a double function. In reptiles, birds, and mammals it is reproductive only and is called the *vas deferens.* A portion of the duct is coiled into the *epididymis.*

The Female Organs.—The female gonads are the ovaries. The ducts are oviducts, and in most vertebrates are split from the body wall as *mullerian* ducts. In a few fishes, however, the duct splits from the pronephric duct.

The oviducts open by a funnel into the coelom in close proximity to the ovaries. They unite to form a uterus which is variously modified within the groups. The uterus opens to the outside through a single tube, the vagina.

CHAPTER XXIX

CHORDATE ORGANIZATION (Cont'd)

FROG

Phylum: Chordata
Class: Amphibia
Order: Anura
Family: Ranidae
Genus: Rana
Species: pipiens

The frog is chosen to illustrate the phylum because of its intermediate position anatomically, and because of its wide distribution and abundance. It is not a typical amphibian, salamanders filling that position more satisfactorily because of their more nearly equal fore and hind limbs and long tail. It represents very well, however, all the transitional characters of vertebrates, having a larval aquatic stage during which it breathes through gills, and an adult amphibious stage in which it breathes both through lungs and through a moist skin, so that it can live equally well in water and on land.

It is a cold-blooded animal, its temperature varying with the environment. It always has, however, a slightly higher temperature in cold weather and a slightly lower temperature in warm weather so that the frog can stand any temperature except freezing, and can even freeze for a short time and revive. Frogs are found, therefore, all over the world except in the arctics.

Seasonal Changes.—Frogs are found in damp places near streams or ponds. A few species wander inland but must return in the spring to lay their eggs in gelatinous masses near the edge of a stream.

During the spring and summer they feed actively so that the fall finds them fat and well nourished. With the increasing cold, inactivity sets in, and they retire below the frost line to bury themselves in the mud at the bottom of a stream. Metabolism is reduced to such a low ebb that sufficient oxygen can be produced through the moist skin even though covered with mud. They draw gradually on the well-stocked tissues, and emerge, lean and hungry, in the spring.

Behavior.—The behavior of the frog is decidedly stereotyped, and the only emotion registered is fear. Nearly all its self-initiated reactions can be classed as instincts, a term which is ambiguous, but which is used here in the sense that no education is required. The instincts of the frog are not nearly as complex as those of many insects.

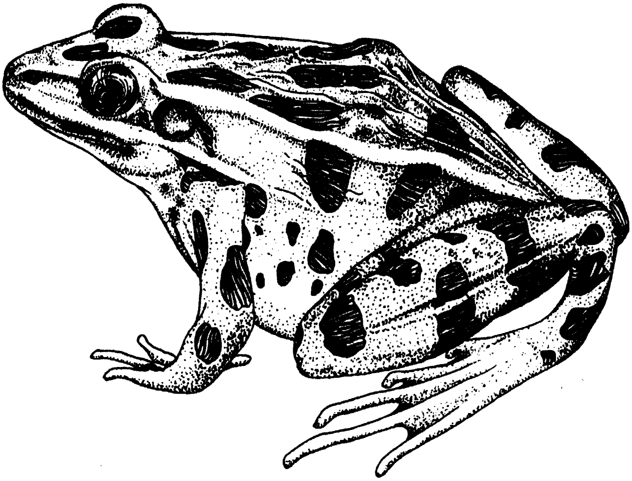


Fig. 317.—*Rana pipiens.* (Drawn from life by Anne Young.)

Yerkes claims that a frog may be taught to follow a path in a labyrinth after about one hundred trials, and that the associations once formed may last for over a month. The frog is easily confused, however, even after it has learned the route, and all the investigators who have worked on the frog have come to the conclusion that while he has a dawning mind, he is a very stupid animal.

Croaking.—The vocal cords are a pair of elastic bands which extend lengthwise across the larynx at the entrance to the lungs. By forcing the air from the lung over the vocal cords into the mouth cavity, the croaking sound can be produced. It is repeated by alternately passing the air between mouth and lung, and can be accomplished as well under water as on land. The croak can be induced by gently stroking the sides.

Eating.—The frog is attracted by moving objects, and has apparently no preferences. Any small animal moving across his field of vision may evoke a response by causing the secretion of lymph in the sublingual glands.

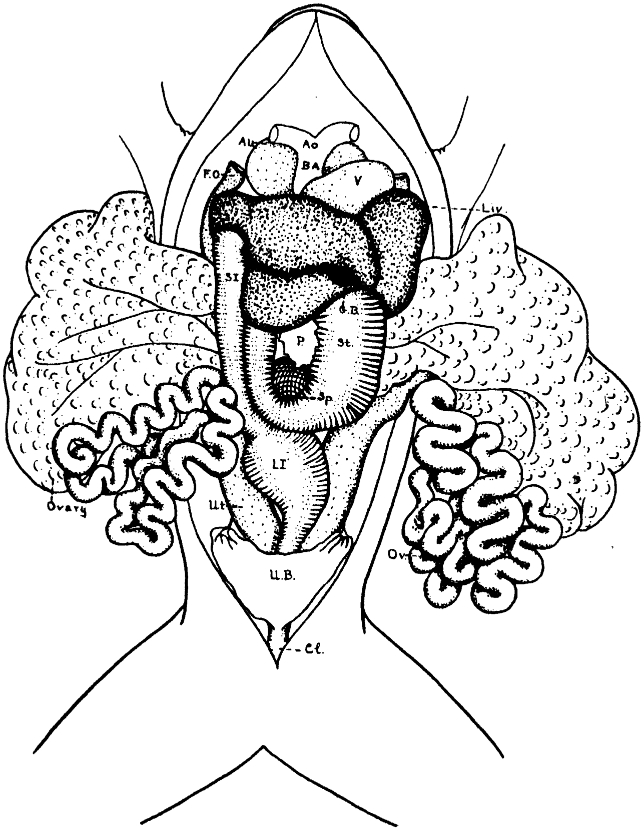


Fig. 318.—Dissection of female frog, semidiagrammatic (life size). *Ao*, Aortic arch; *BA*, bulbus arteriosus; *Au*, auricle; *V*, ventricle; *FO*, funnel of oviduct; *Liv*, lobe of liver; *GB*, gall bladder; *SI*, small intestine; *St*, stomach; *P*, pancreas; *Sp*, spleen; *LI*, large intestine; *Cl*, cloaca; *UB*, urinary bladder; *Ut*, uterus; *Ov*, oviduct; *Ovary*, containing eggs.

The tongue of the frog is extensile. The anterior end is attached to the tip of the lower jaw. The free, posterior end is forked, and the surface is covered with a sticky secretion.

When the sublingual sac is full, the contraction of the mylohyoid muscle in the throat forces the lymph into the tongue, thus shooting it forward. The tongue moves forward rapidly, wraps its forked end about the object which adheres to the sticky surface, and is as quickly withdrawn.

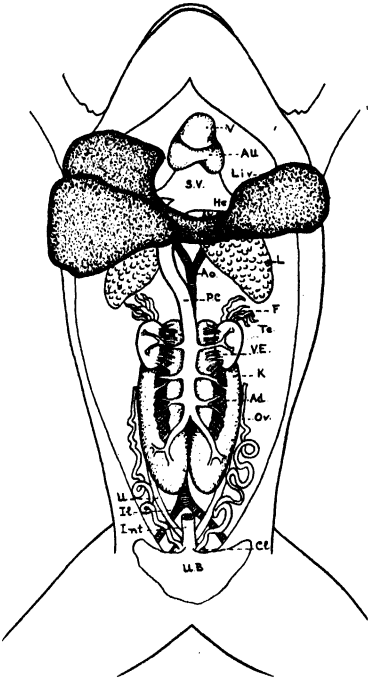


Fig. 319.—Dissection of male frog. Semidiagrammatic, life size. The digestive organs have been removed, and the heart and the lobes of the liver have been turned back to disclose the lungs and show the dorsal aspect of the heart. The urinary bladder is displaced. *V*, Ventricle; *au*, auricle; *S.V.*, sinus venosus; *He*, hepatic vein; *Liv*, liver; *L*, lung; *Ao*, dorsal aorta, showing union of aortic arch; *P.C.*, postcaval vein; *F*, fatty bodies; *Te*, testis; *V.E.*, vasa efferentia; *K*, kidney; *Ad*, adrenal gland; *Ov*, rudimentary oviduct; *U*, ureter; *Il*, iliac artery; *Int*, cut end of digestive tract; *Cl*, cloaca; *U.B.*, urinary bladder. (Dissection and drawing by Anne Young.)

Movements.—The frog moves by leaping or swimming. The strong muscles of the hind leg are used in propulsion, the small fore limbs regulating the direction of the leap. When at rest on land, the hind limbs are folded up under the frog ready for a sudden leap. When at rest in the water, the hind limbs hang obliquely downward in a state of semirelaxation. This position, also, is favorable to sudden withdrawal, since the sudden bringing of the hind limbs up will shoot the frog downward into the water.

Closing the Eye.—The eye protrudes from the head. There is an upper and a lower eyelid which are folds extending from

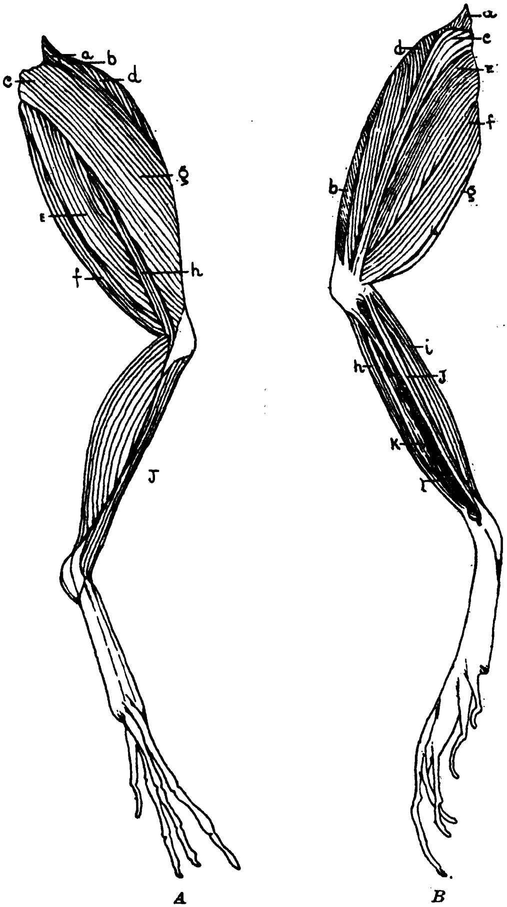


Fig. 320.—Right leg of frog. *A*, Dorsal view. *a*, Tensor fasciae latae; *b*, vastus externus; *c*, vastus internus (three heads of *g*, triceps femoris); *d*, iliacus; *e*, semimembranosus; *f*, gracilis minor; *h*, semitendinosus; *i*, gastrocnemius; *j*, peroneus. *B*, Ventral view. *a*, Tensor fasciae latae; *b*, vastus externus; *c*, sartorius; *d*, adductor longus; *e*, adductor magnus; *f*, gracilis major; *g*, gracilis minor; *h*, extensor cruris; *i*, gastrocnemius; *j*, tibialis posticus; *k*, tibialis anticus longus; *l*, tibialis anticus brevis. The tibiofibula is indicated by cross lines. (Dissection and drawings by Claire King.)

the edge of the orbit above and below the eye. An extension of the cornea, the conjunctiva, is reflected back from the sclerotic coat to cover both lids. The lower lid has two folds: the lid proper and a nictitating membrane. The latter is a semitransparent membrane separated from the lower lid by a furrow.

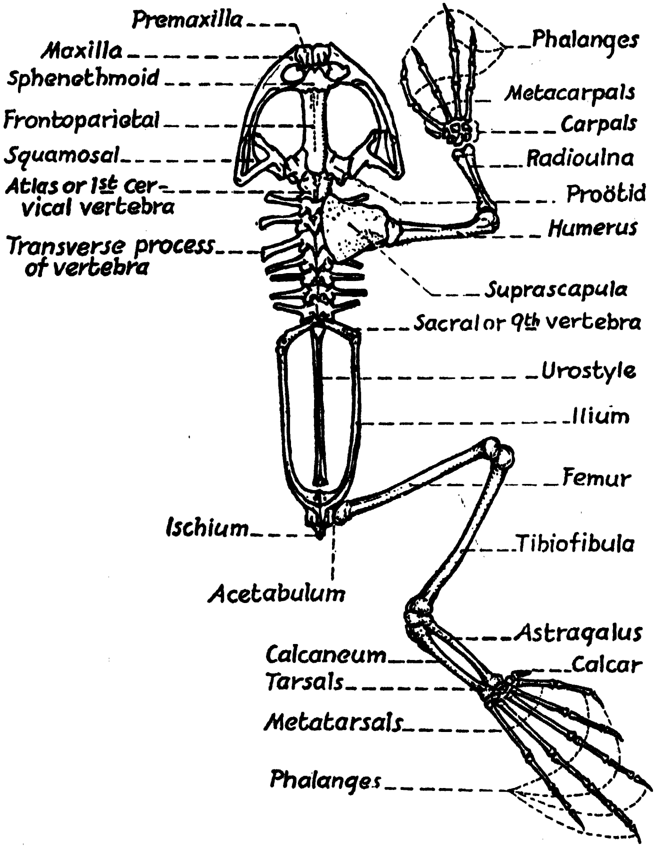


Fig. 321.—Skeleton of frog (dorsal view) with appendages of right side only. (From Beaver: Fundamentals of Biology, The C. V. Mosby Co.)

The eye is closed by the retraction of the eye into its orbit, and not, as might be supposed, by the raising of the lid. The retraction of the eye produces a tension on the tendon attached to the nictitating membrane which causes the membrane to be drawn up over the eye. It never completely covers the eye.

Changing the Color.—Color changes in the frog are protective in that they tend to conceal him from his enemies. These changes are much more definitely developed in the tree frogs than in the leopard frog, although Rana possesses them to a slight degree. They are caused by the expansion and retraction of the black pigment in the chromatophores of the epidermis, and are under the control of secretions from the pituitary gland.

A yellow pigment, lipochrome, lies under the chromatophore, and the black pigment may be spread either under or over the yellow. If it is spread under the yellow, a green color is produced, if over the yellow, a dark coloration results.

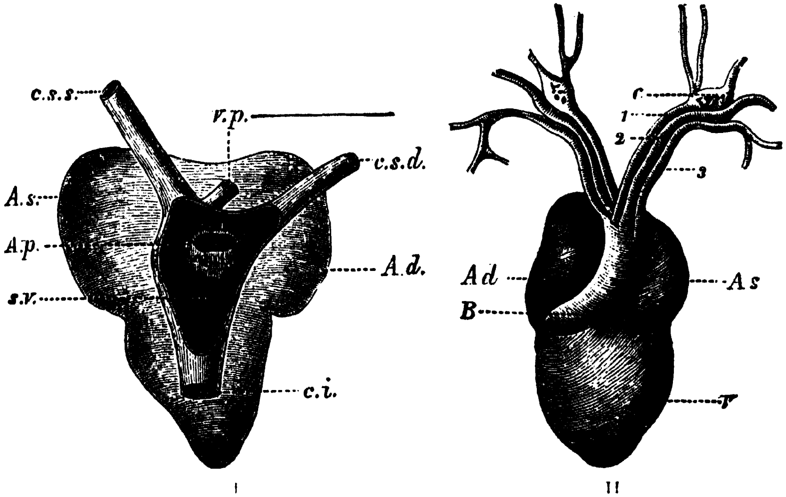


Fig. 322.—Heart of frog. I, Dorsal view. II, Ventral view. *V*, Ventricle; *Ad*, right auricle; *As*, left auricle; *B*, bulbus arterosus; *s.v.*, sinus venosus; *A.p.*, opening into right auricle; *c.s.s.*, left anterior vena cava; *c.s.d.*, right anterior vena cava; *c.i.*, posterior vena cava. (After Ecker.) (From Zoethout: Textbook of Physiology. The C. V. Mosby Co.)

The changes are stimulated by light, since they do not take place if the eyes are blinded. The color change produced by any particular light stimulus is such as to bring the color of the frog most closely into accord with its environment.

Characteristics of the Frog

1. The skin is smooth and slippery from a mucous secretion. There are no exoskeletal structures.

2. There is no neck and no tail.
3. There is a single posterior aperture, the anus.
4. There is no external ear.
5. The teeth are small and conical. They are found on the jaws and on the vomers.
6. The coelom is divided by an oblique transverse septum into an antero-ventral pericardial cavity, and a pleuroperitoneal cavity.

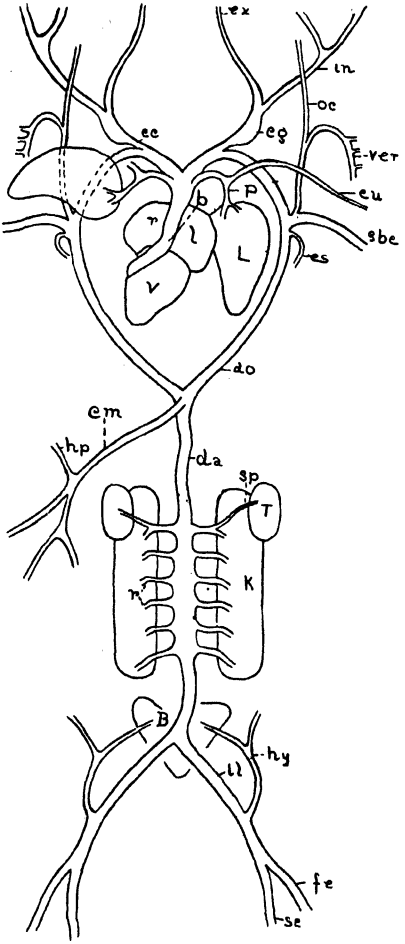


Fig. 323.—Diagram of the arterial system of the frog viewed from the ventral surface. *ex*, External carotid; *in*, internal carotid; *cg*, carotid gland; *c.c.*, common carotid; *oc*, occipital; *ver*, vertebral; *cu*, cutaneous; *p*, pulmonary; *b*, bulbus arteriosus; *l*, left auricle; *r*, right auricle; *v*, ventricle; *sbc*, subclavian; *es*, esophageal; *ao*, aortic arch; *da*, dorsal aorta; *cm*, coeliaco-mesenteric; *hp*, hepatic; *sp*, spermatic; *r*, renal; *il*, iliac; *hy*, hypogastric; *fe*, femoral; *sc*, sciatic; *L*, lung; *K*, kidney; *T*, testis; *B*, bladder.

7. The hind limbs are greatly enlarged, and the fore limbs are correspondingly reduced.

8. The radius and ulna, and the tibia and fibula are fused into single bones of double origin.

9. There are four digits on the hand. The phalanges have the formula 3-3-2-2.

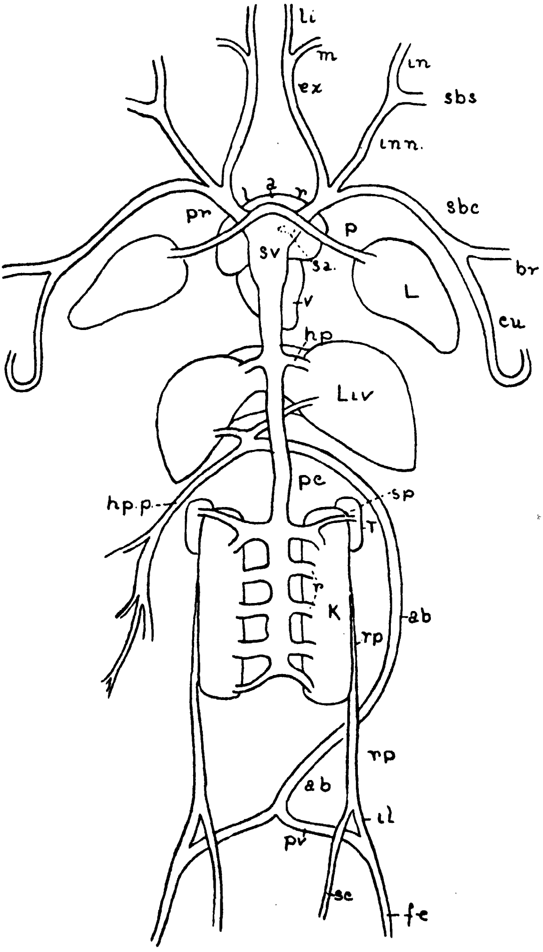


Fig. 324.—Diagram of the venous system of the frog viewed from the dorsal surface. The sinuauricular aperture to the right auricle is indicated and the ventral abdominal vein is displaced to the right. *li,* Lingual; *m,* mandibular; *ex,* external jugular; *in,* internal jugular; *sbs,* subscapular; *inn,* innominate; *sbc,* subclavian; *br,* brachial; *cu,* cutaneous; *p,* pulmonary; *pr,* precava; *sv,* sinus venosus; *a,* auricle (*r,* right; *l,* left); *v,* ventricle; *s.a.,* sinuauricular aperture; *pc,* postcava; *hp,* hepatic; *hp.p.,* hepatic portal; *sp,* spermatic; *r,* renal; *rp,* renal portal; *ab,* abdominal; *il,* iliac; *pv,* pelvic; *sc,* sciatic; *fe,* femoral; *L,* lung; *Liv,* liver; *K,* kidney; *T,* testis.

10. There are five digits and a small prehallux on the foot. The phalanges have the formula 3-4-3-2-2.

11. The vertebral column contains:

    One cervical vertebra, articulating on a double occipital condyle.
    Seven thoracic vertebrae with lateral transverse processes which articulate with short cartilages, sometimes falsely called ribs.
    The sacral vertebrae are fused into an ilium.
    The caudal vertebrae are fused into a urostyle.

12. There are no cranial flexures.

13. There are but ten cranial nerves.

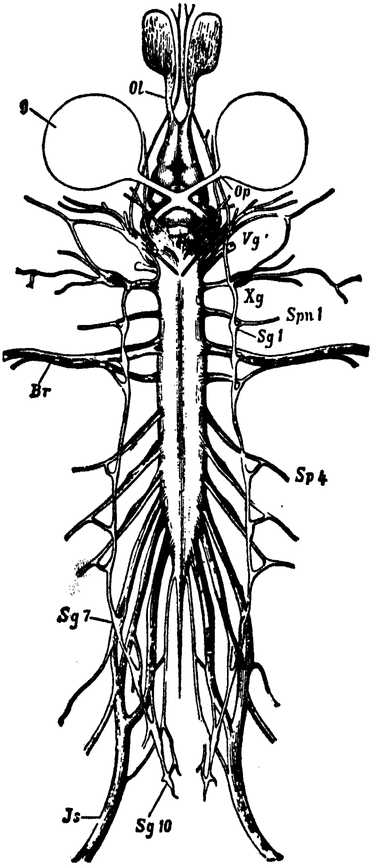


Fig. 325.—Ventral view of the nervous system of the frog. *Br.* Brachial plexus; *Js*, sciatic nerve leading from the sciatic plexus; *O*, eye; *Ol*, olfactory nerve; *Op*, optic nerve; *Sg* 1-10, ten ganglia of the autonomic nervous system; *Spn* 1, first spinal nerve; *Sp* 4, fourth spinal nerve; *Vg*, trigeminal ganglion; *Xg*, ganglion of tenth cranial nerve (vagus). (After Ecker.) (Reprinted by permission from Woodruff: Foundations of Biology. Published by The Macmillan Co.)

14. The lens of the eye is spherical; the pupil is oval; and the iris is colored.

15. There is a columella in the middle ear.

16. There is a gall bladder.

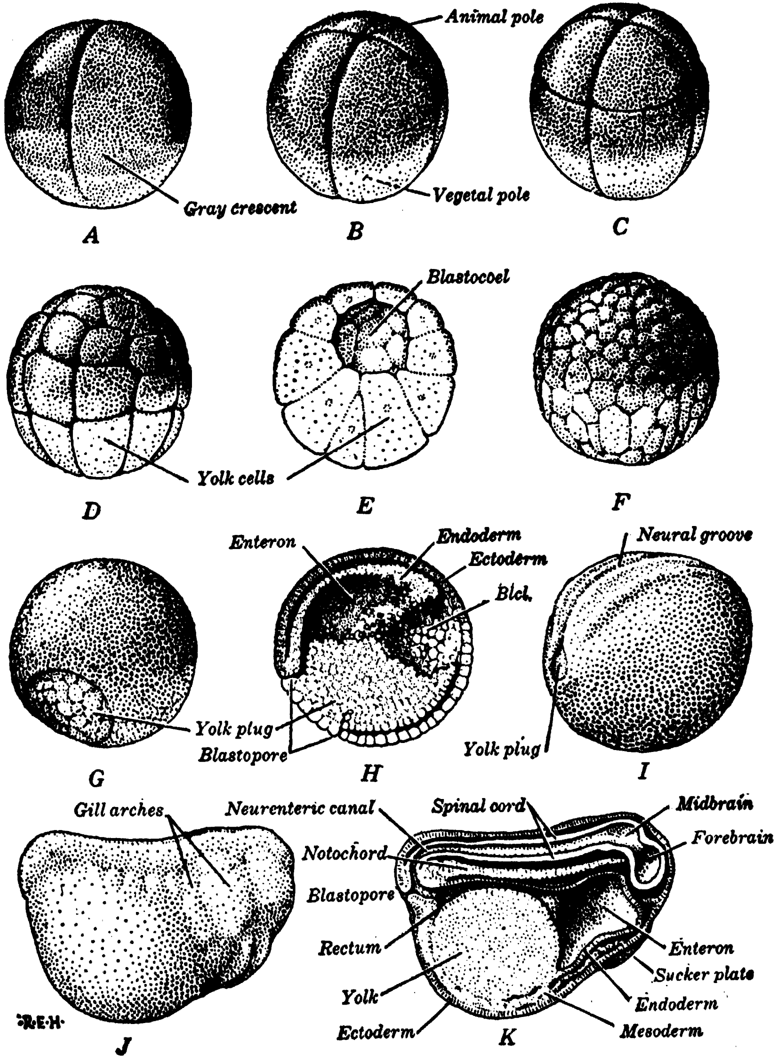


Fig. 326.—Early development of the frog. *A, B, C.* 2-, 4-, and 8-celled stages of dividing egg; *D*, early blastula; *E*, section of *D*; *F*, late blastula; *G*, early gastrula; *H*, late gastrula with neural groove; *I*, section of *H* showing germ layers; *J*, older embryo with neural groove closed; *K*, section of *J*. (Reprinted by permission from Woodruff: Animal Biology. Published by The Macmillan Co.)

17. There is a cloaca.

18. The heart is three chambered, having two auricles and one ventricle.

19. There is a double circulation, but the cold-blooded condition prevails because the blood streams are not completely separated.

20. The red blood corpuscles are nucleated.

21. There is one complete aortic arch.

22. There is an hepatic portal and a renal portal system.

23. The kidney is a mesonephros. It is a long, narrow organ lying against the dorsal body wall. A yellowish adrenal band lies embedded along its length. It is retroperitoneal.

24. The pronephros functions in the embryo.

25. The larval tadpole is aquatic, breathing by gills.

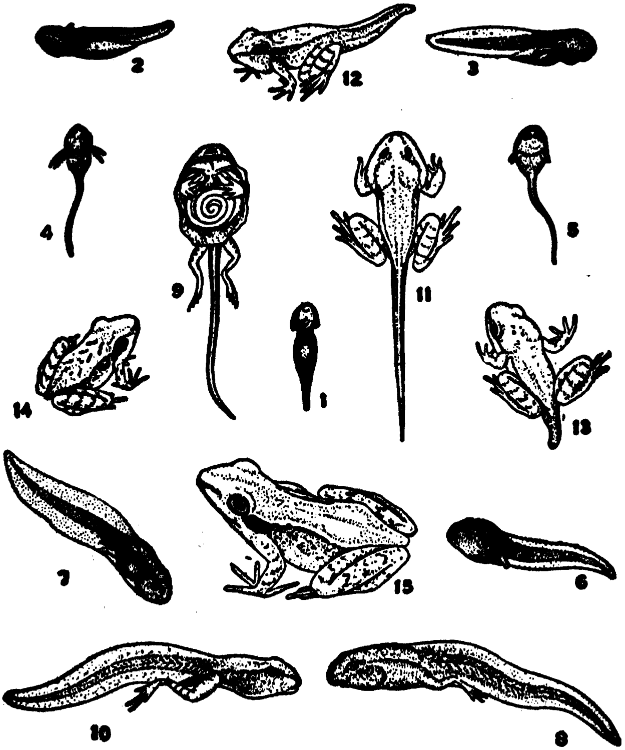


Fig. 327.—Larval development of the frog, and metamorphosis. *1*, Tadpole just hatched, dorsal aspect; *2*, *3*, older tadpoles, side view; *4*, *5*, later stages, dorsal views showing external gills; *6*, tadpole with gills covered; *7*, older stage, right side showing hind limb; *8* and *10*, lateral view of two later stages showing development of hind limbs; *9*, dissection of tadpole to show internal gills, spiral intestine, and anterior legs developed within operculum; *11*, advanced tadpole just before metamorphosis; *12*, *13*, *14*, stages in metamorphosis, showing gradual resorption of tail; *15*, young frog after metamorphosis. (From Newman, after Leuckart and Nitsche.) (Reprinted by permission from Woodruff; Animal Biology. Published by The Macmillan Co.)

CHAPTER XXX

ADAPTATIONS IN ANIMALS

Throughout this book life has been presented as a phenomenon of continual adjustment of internal relations to external relations, the entire life of the organism being one series of reactions after another, the ultimate aim of which is the preservation of the individual and the perpetuation of the race. That these reactions have been stamped upon the organisms as internal and external modifications of structure and behavior, and have been passed on as hereditary structures and instincts, is the basis of the evolution theory, which is a theory of development applied to the race.

Whether the environment has been functional in establishing these modifications, or whether chance has been kind in fitting the modification to the proper environment, is open to argument, but the fact remains that only in relation to the environment does the structure take on any meaning.

If the adaptations were all perfect, or if only useful adaptations could be found, the task of assigning a cause might be simpler; but there is so much that is imperfect, so much that is only half done, and so much that is left over—mere vestiges of past usefulness—that, not only the adult, but also the embryologic development and much of the ancestral history must be known before the adaptations can be logically explained; for ancestry has left its mark on the embryo as well.

Recapitulation

Ernst Haeckel, the German embryologist, believed that through embryology alone the racial development could be traced out. The recapitulation theory expresses his thought in the phrase, "ontogeny repeats phylogeny," or the development of the individual repeats the development of the race. Haeckel pointed out that as all animals begin life as a single cell, this indicates the Protozoa as the original ancestors of the race. The blastula stage represents colonization in the Protozoa; the gastrula, the two-layered coelenterate. He found that the rotifers so closely resembled the trochophore larvae of the annelids that he believed them to be the ancestral group, the annelid passing through the adult rotifer stage in its development.

The recapitulation theory received something of a blow when the primitive annelids turned out to be elongated forms instead of the greatly shortened rotifers, and the absurdity of carrying this theory to an extreme became apparent. Nearly all of Haeckel's specific examples of adult larvae have had a similar fate, but the idea involved in the theory is a fruitful one, nevertheless, and has been of the greatest value in establishing relationships.

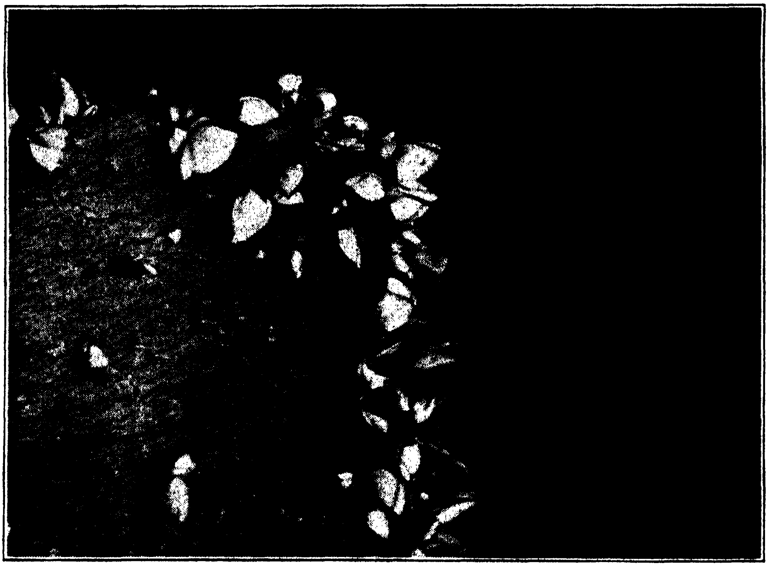


Fig. 328.—Goose barnacles (Lepas). Specimens attached to a board found floating in the Gulf Stream. (Copyrighted by the General Biological Supply House, Chicago, Ill.)

Embryologic data alone are responsible for establishing the true place in nature of the goose barnacle and the strange formless parasite in the abdomen of the crab, called Sacculina because of its saclike form. The barnacle has been variously classified in the past, some placing it among the Molluscs because of its hard shell, others calling it a prochordate or placing it in a phylum all its own. Thomson, who worked out the embryology of the barnacle, found that it had a true nauplius larva which is the characteristic larval form of the Crustacea, the aquatic arthropods. Moreover, the nauplius larva which has three pairs of appendages developed into a

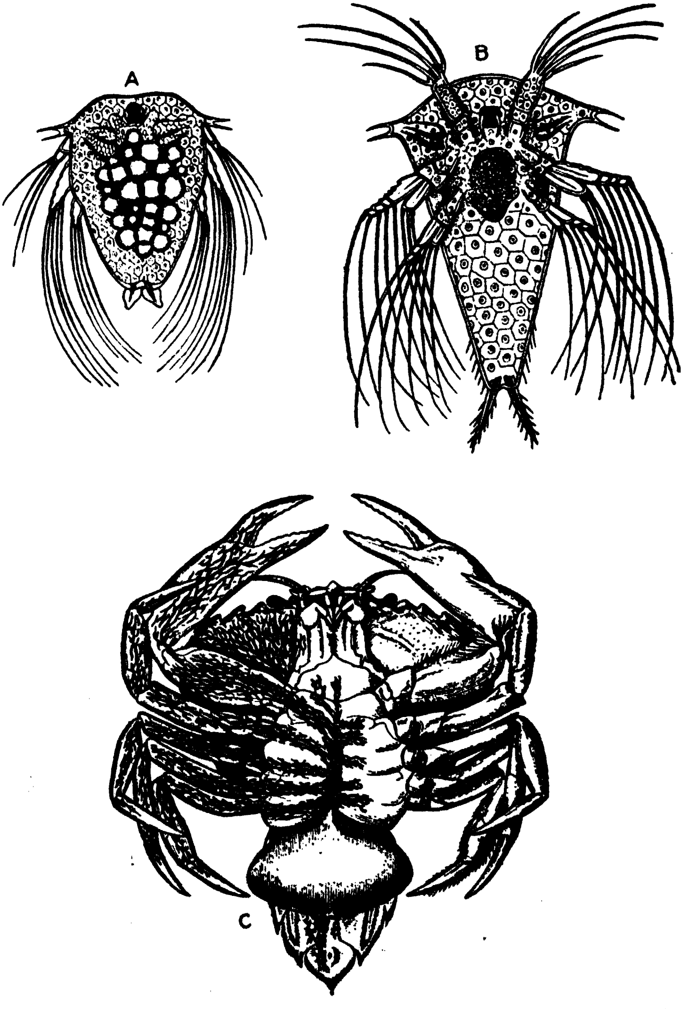


Fig. 329.—Sacculina. An arthropod whose position is determined by the larval development. *A* and *B*, Larval stages with jointed appendages; *C*, crab infested with Sacculina. The ramifying roots of the mature Sacculina are shown on the right side only. (Reprinted by permission from Lull: Organic Evolution. Published by The Macmillan Co.)

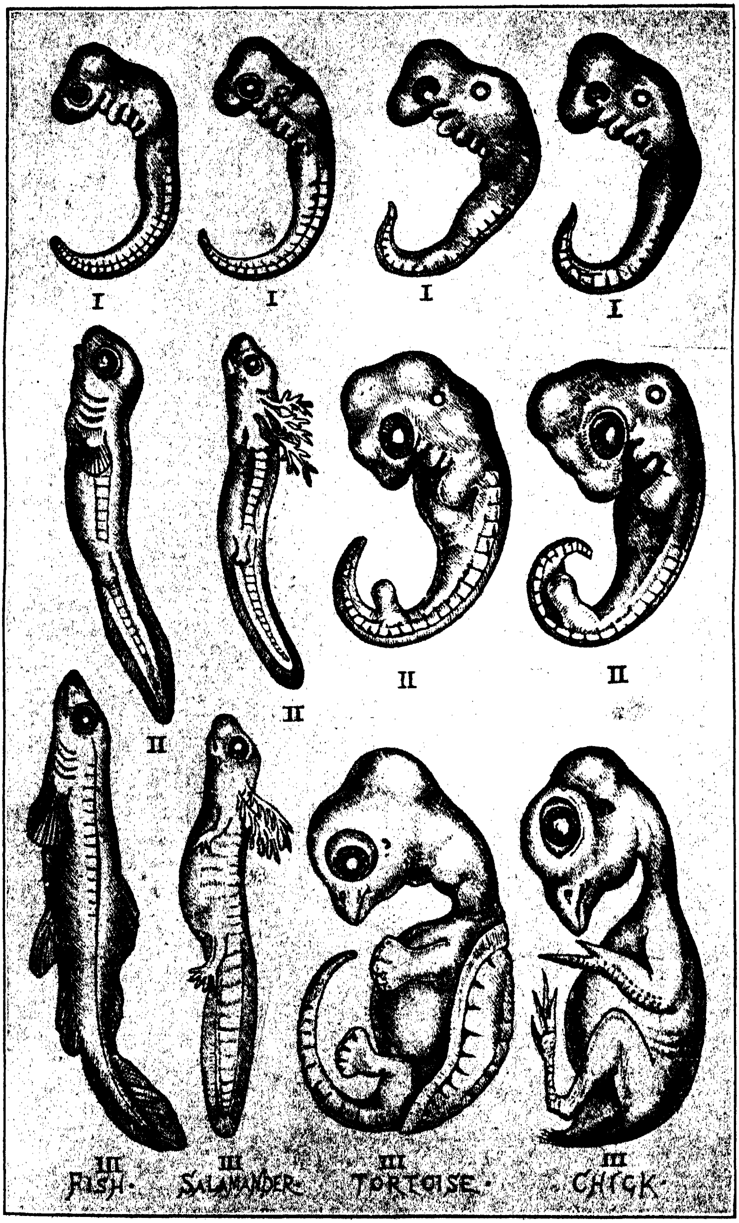
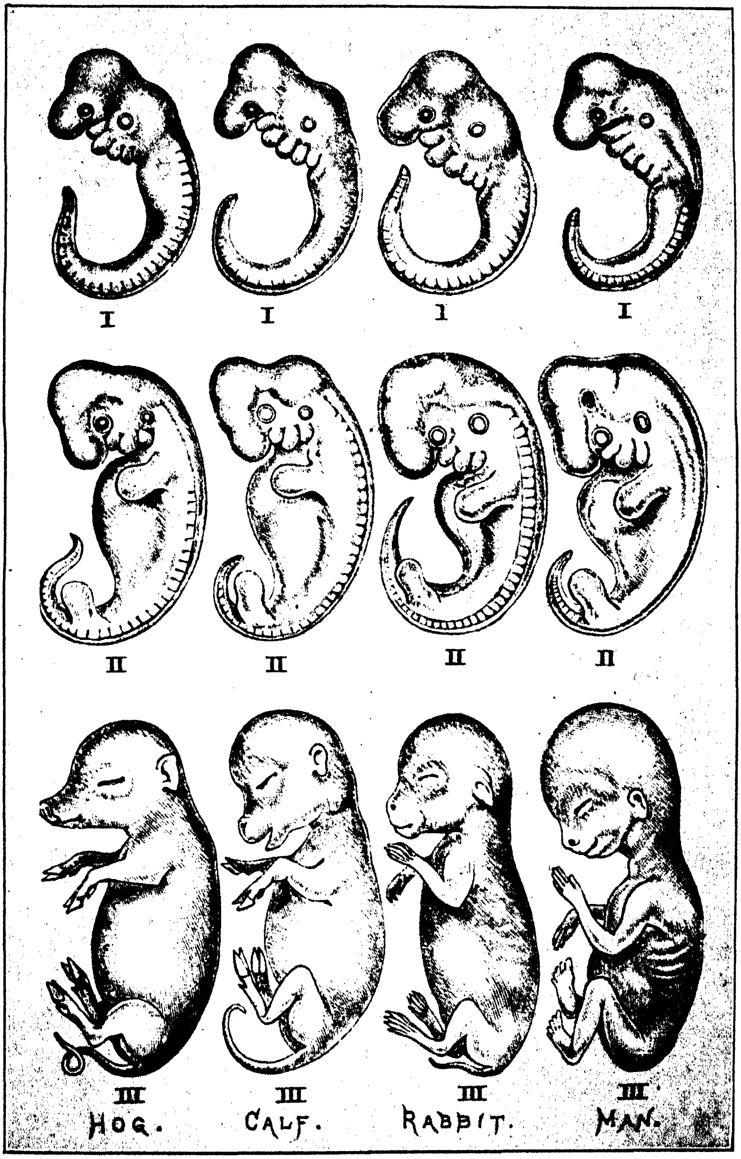


Fig. 330.—Diagram showing parallel stages in the development of vertebrate embryos. Note the gill slits in the early stages of all types. (After



Haeckel.) (Reproduced by permission from Romanes: Darwin and After Darwin. Published by The Open Court Publishing Co.)

bivalved type very similar to the Cypris, a minute cirripede crustacean. At this point the little Cypris form settled down on its antennae and developed into the adult barnacle, the bivalved shell separating into several parts, and the jointed appendages of the arthropods extending through the valves. These were formerly believed to be tentacles.

More remarkable still is the history of Sacculina which passes through the same nauplius and Cypris stages as the barnacle, and settles down on its antennae which it thrusts into the body of a crab. All the tissues of the Cypris then become fluid as do the tissues of a butterfly larva in a cocoon. The antennae then become hollow tubes through which the fluid tissues flow out into the tissues of the crab. In the blood sinuses of the crab they round up into a ball and float to the intestines where they send out rootlike processes into the body of the crab penetrating the whole abdomen. Thus they absorb the body fluids of the host and maintain a completely irresponsible existence. It would never have been correctly classified except for the principles of the recapitulation theory.

In the vertebrates the phylogenetic relationships are beautifully illustrated in the embryonic development. The circulatory, respiratory, and nervous systems pass through stages identical in all vertebrates; each successively higher group carrying the process one step further. The gill slits which appear in all vertebrate embryos present the most dramatic illustration. These slits cut through from the pharynx to the wall of the neck and in the fishes and larval salamanders are the only means of acquiring oxygen. In the terrestrial forms the slits close up, but the first gill slit in mammals persists as the eustachian tube. In the fishes this slit forms the spiracle.

The mammalian ear is developed in connection with the gill structure, the visceral arches which are the bony supports of the fish gills contributing the three small bones of the ear. Even in the fishes the arches of the first two gill slits were modified to form the lower jaw, and through successive positions in the skull of the higher vertebrates they attain their final position in the middle ear.

In some abnormal human embryos duplicate ear structures have been known to develop in connection with the other gill slits, and occasional cases are cited in which the slits persist after birth, permanent openings through which the food trickles from the throat.

In the mammalian adults, too, are many vestigial structures with no apparent use, which can be explained on the basis of their usefulness in other forms. Thus the vermiform appendix, the blind caecum on the large intestine, which often forms a trap for excretory matter and thus becomes a source of poison in the body, once played an important digestive function in the herbivorous animals. The whale has concealed in the flesh underneath the finlike folds of skin with which it simulates the locomotion of the fishes, the bones of the mammalian fore limb with which its ancestors once trod the firm ground, and man conceals quite as successfully the six coccygeal bones at the end of the vertebral column which formed the base of all vertebrate tails.

All useful adaptations bear a direct relation to the procuring of food, the safety of the individual, or the preservation of the race. Some which adapted the individual for its own safety were of no use in preserving the race, as in the case of the great dinosaurs which were safe from attack when food was plentiful but were outrun by the smaller, fleeter forms when the unfavorable conditions of a changing climate took them unawares. Overspecialization has always led to the extinction of the race.

The greatest diversity of form is found where there is the greatest diversity of conditions—in the terrestrial forms. The land animals have had to contend with many upheavals of the earth's surface; with alternate moisture and dryness, heat and cold. Today we find them living on the earth and under the earth, in the trees and in the air. They live on the mountain tops and in valleys, in deserts and in swamps, in the forest and on the grassy plain. Some of them have even returned to the water.

Protective Adaptations

Adaptations which have a protective value are found in all groups of animals. Of especial interest are those which form color patterns and mimicking structures, which tend to obliterate the object from view or to confuse the attacking organism by a sudden change of color or a merging with the landscape when alighting, so that they effectively disappear from view. In the bright green grass, the katydid and the green snake defy detection; on the green leaves the bright green caterpillars will escape notice. The dead leaf butterfly, the walking stick, and the geometrid caterpillar are all such perfect mimics that when at rest they might easily be taken for parts of the plants on which they rest.

Many colors which are striking on the wing are obliterative in the bush. Thus the grouse can scarcely be located on the ground, and butterflies and moths with brilliant under wings are completely obliterated when they alight and fold the inconspicuous outer wings down over the brilliant ones. The chameleon changes the color of its skin pattern according to the color of its background as do many frogs, salamanders, and fishes. Many sea forms have a changing iridescence, and the flounders which lie on the sands at the bottom of the shallow harbor waters are distinctly marked on the dorsal side according to the coarseness of the sands. If placed on a black and white checkerboard, these flounders assume large black and white areas; if placed on fine sand, the pattern is finely speckled and scarcely visible from the top. The ventral sides of these fishes are white, and if bottom side up, they would be instantly spotted.

Warning colors are claimed for many deadly forms, such as the coral snake and the black banded hornets, beetles, and other stinging insects. Often noxious odors are emitted which overcome the effect of a too conspicuous pattern, as in the skunk with its startling white stripe.

It is interesting to note that many of these deadly forms have mimics among the innocent and harmless ones. There are flies which not only look like bees and wasps but hum like them, thus assuring them safety from the enemies which may have tasted or been stung by the deadly types. The coral snake has a mimic which can only be detected by the expert who would note the difference in color alternation. The mimic is a perfectly harmless snake but is avoided because of the deadly bite of the coral snake.

Adaptation to Speed

One of the most beautiful adaptations in the animal kingdom is that which provides for swift movement. Flight was a prime necessity for the grazing animals of the plains, and it was speed which determined the success of the mammals over the cumbersome dinosaurs which had previously dominated the whole animal world by sheer bulk.

The fastest moving forms, whether aquatic or terrestrial, are built upon a similar plan, made possible by the establishment of bilateral symmetry in freely moving forms. The body is a fusiform, or spindle shape, smoothly rounded and shorn of all unnecessary excrescences, a shape which offers the least possible resistance to the opposing currents of water or air. On similar plans are built all speed boats and racing cars.

In terrestrial forms, speed in covering the ground is accomplishing by running, an accomplishment which has reached its height in the mammals. The elephants, camels, and horses are the best adapted types, each adapted to speed in a different type of environment. The elephant is constructed to carry a heavy weight for crashing through the underbrush of the jungles. The camel's cushioned feet yield to the desert sands, and in the race horse the single, hard hoof is capable of long continued speed over a hard, unyielding course. With its head and neck extended, ears thrown back, and legs forward, one gently curving contour from nose to tail, the horse is at one with its environment.

This mechanism has been attained by the gradual lifting of the body from the ground, by the elongation of the limb bones, and by the lifting of the foot to throw the weight from the sole forward to the toes, and finally to the tip of the digits. Lengthening of the limbs at the distal rather than at the proximal end allows for the concentration of the heavy muscles on the relatively short thigh, raising the center of gravity and giving a stronger pull to the pendulum movement of the

Fig. 331.—A Miocene landscape in Switzerland. (After Heer.) (Reprinted by permission from Plants of the Past, by Knowlton. Published by Princeton University Press.)

limbs. In the elephant, which has the greater weight to carry, the muscles are concentrated on the distal segment.

The lengthening of the distal segments in the horse is accomplished by the loss of accessory digits. The middle finger and toe are provided with a hoof, in place of the nail or claw, since it is better adapted to bear the weight. The wrist and ankle bones are fused into a single "cannon" bone. The ulna and fibula are lost, since rotation of the limb is no longer a necessity. All segments are elongated to allow the maximum swing of the pendulum.

This swing is made possible by the tongue and groove joint which permits a wide arc of movement in a single plane. All joints of the limbs have this type of joint except the hip and shoulder where the ball and socket joint is retained. This is necessary to prevent interference of fore and hind limbs while running, and to allow the animal to lie down and get up without undue difficulty.

The loss of utility in the fore limbs, which in other forms are used to get food, and the raising of the body from the ground, have necessitated a lengthening of the head and neck to permit the animal to graze without bending the knees. This necessitates the raising of the eyes to allow for the longer crowns of the grazing teeth, and to provide for a wide range of vision while eating, a matter of importance to the animal of the open plain. The brain case is large, and the eyes are protected by a bony socket. The horse is intelligent on a low plane, but no amount of training will overcome the instinct to run away when thoroughly startled.

The Geologic Timetable

The geologic timetable in Fig. 332 shows that five major periods have elapsed since the beginning of time. Even the earlier geologists found the earth's strata to be divided into five well-defined series, always with gaps between, and even between lesser divisions within the eras. These gaps possibly indicate surface volcanic activity or other violent disturbance. Whatever their cause, they have served the geologist well in marking off the beginning and end of the large eras and their subdivisions.

PSYCHOZOIC	POST GLACIAL	AGE OF MAN
CENOZOIC		
QUATERNARY	PLEISTOCENE	AGE OF MAMMALS AND ANGIOSPERMS
	PLIOCENE	
TERTIARY	MIOCENE	
	OLIGOCENE	
60,000,000 YEARS	EOCENE	
	EPIMESOZOIC INTERVAL	
MESOZOIC		
LATE	CRETACEOUS	AGE OF REPTILES AND GYMNOSPERMS
	COMANCHEAN	
EARLY	JURASSIC	
180,000,000 YEARS	TRIASSIC	
	EPIPALEOZOIC INTERVAL	
PALEOZOIC		AGE OF AMPHIBIANS
LATE	PERMIAN	
	PENNSYLVANIAN	AGE OF FISHES AND PTERIDOPHYTES
MIDDLE	MISSISSIPPIAN	
	DEVONIAN	
	SILURIAN	AGE OF INVERTEBRATES AND THALLOPHYTES
EARLY	ORDOVICIAN	
500,000,000 YEARS	CAMBRIAN	
PROTEROZOIC 1,000,000,000 YEARS		AGE OF PRIMITIVE LIFE
ARCHEOZOIC 2,000,000,000 YEARS		AGE OF UNICELLULAR LIFE

Fig. 332.—The geologic timetable.

In any particular locality the rocks on the surface may be of any era, but the rocks under the surface will be of an older period, for the older strata always lie deeper than the newer ones. Thus in Montana where the Cenozoic rocks are found, Eocene strata lie under Oligocene strata, and Oligocene under Miocene. In the Grand Canyon where the Paleozoic history is written in the rocks, the whole series from the Cambrian up to the Permian can be seen, each stratum of rock under the one of the next succeeding period.

The thickness of the strata gave the first clue to the duration of the eras, and estimates were made on the rate of sedimentation of the different grades of rock. More accurate determinations have been made possible by reckoning the disintegration rates of radioactive elements like uranium. The ultimate form of all radioactive elements is the inert lead. The amount of lead, therefore, in any mass of rock may be an indication of the length of time required by a like mass of uranium to disintegrate into lead. Disintegration rates are constant and not dependent on temperature or humidity changes as sedimentation rates are.

Thus, while the geologists have given us an accurate picture of the series of strata and their relative durations, it has remained for the physicist to provide the most accurate basis for estimating actual time. On that basis the major areas are estimated as of approximately the following durations:

Cenozoic	60,000,000 years
Mesozoic	180,000,000 years
Paleozoic	500,000,000 years
Proterozoic	1,000,000,000 years
Archeozoic	2,000,000,000 years

Even on this basis it will be noted that the later eras have tended to become relatively shorter, as our knowledge about them has become progressively greater. Very little is known of the life in the Proterozoic, and the Archeozoic rocks are the unstratified rocks of the earth's surface, probably existing before life began. The Proterozoic era must have seen the entire invertebrate evolution, for representatives of all the major invertebrate groups are found among the Cambrian fossils. As all invertebrate groups, even the unicellular forms, tended to form external shells of calcium carbonate, of chitin, and even of glass, it is probable that the violence of the upheavals during the Proterozoic ground the shells into chalk cliffs but left no impression of their forms. Bacteria have been identified in Proterozoic rocks and the presence of iron ore in the rocks is an indication of bacterial action, for oxidized iron is deposited in swamps where the iron bacteria are active today. Graphite, too, is a product of bacterial action on organic matter. These facts indicate the presence of organic life, but the record of their development is lacking.

The life of the three succeeding eras has been well preserved, however. Possibly the conditions of the Cambrian were less violent. At any rate, the conditions favoring fossilization existed, for the hard parts of all the groups have been preserved.

The methods of fossil preservation have been various. The sudden cold of glaciation in the late Cenozoic Era preserved many forms intact, and whole insects were preserved in the amber which was exuded from the pine trees and hardened by evaporation. Petrifaction with replacement, molecule by molecule, of the organic material by minerals in solution was the more common method, and the histologic structure of tree trunks was often accurately preserved in this way. In other cases natural molds were formed. The organic material disintegrated inside a hardened caste, preserving the shape but not the structure. Such castes were formed when the inhabitants of Pompeii were overtaken by the sudden eruption of Vesuvius. Materials poured into these molds have revealed the actual positions in which these unfortunates were overtaken. Mineral matter seeping into such cavities have preserved the shapes of even such soft structures as jellyfishes. Footprints have also been preserved in this way.

The coal deposits furnish a wealth of plant and animal remains, and give an excellent picture of the early adaptation of living organisms to a terrestrial mode of life. The preservation of the plant tissues which made these deposits was probably due to conditions such as are found in peat bogs today. The accumulation of organic acids caused by the sluggish conditions prevents the usual bacterial action, and the organisms are thus preserved without decay. But during the course of time the tissues are deprived of their gaseous contents, hydrogen and oxygen, and only the solid carbon remains. Subjected to many ages of pressure, this solid substance has formed the coal. During the successive stages various grades of coal were formed, according to the amount of gaseous material removed. Thus the harder the coal, the purer the carbon, and the higher the fuel value. Anthracite coal, therefore, is the most efficient fuel, the value decreasing through the various grades of bituminous coal to the peat. From the coal various other fuels can be derived, such as kerosene, gasoline, and the long list of coal-tar products familiar to the organic chemist. The coal deposits, therefore, furnish a large percentage of the fuel of the world, and through the mining of the deposits many valuable plant and animal remains have come to light.

The ancestral ferns, gymnosperms, and angiosperms are all found in such deposits, together with many amphibians and reptiles. Mammals, too, were similarly caught in quicksands; and the oil oozing from the shale beds in the Cenozoic Era formed traps for many carnivorous animals by hardening from evaporation until it would support the weight of small animals but would give way under the larger types which pursued them. Caught in the gluey substance, they enticed still larger animals until whole associations of carnivorous animals came to be buried at one time.

The bones of vertebrates were peculiarly resistant to destruction, and the history of the vertebrates is more complete than that of any other group. Many series of progressive adaptations to special modes of life have been worked out, among which those of the elephant, camel, and horse, are significant for their completeness. The development of the horse has been chosen as an example.

Rhythms of Nature

The end of each major geologic era has been marked by some great upheaval of the earth's surface. The end of the Paleozoic was marked by the formation of the Appalachian Mountain range with all its concurrent surface undulations, and the Mesozoic ended with the Rocky Mountain upheaval. The height and sharpness of the peaks in the Rockies are marks of their geologic youth.

With each change there has been a drastic alteration in plant and animal life. A few especially well-adapted and usually generalized types have persisted, but the bulk of the specialized types has become extinct. Invariably the dominant life of the new period is of a higher organization than the one preceding, and it is a significant fact that in the periods just preceding each great revolution the primitive types of the next succeeding dominant life have begun to appear.

A clue to the species changes that are at the root of these evolutionary advances is found in the work now going on in genetics with induced mutations. Gamma rays, cosmic rays, and ultraviolet rays have all been found effective in speeding up mutation rates in species now existing. If external control is possible now, it naturally follows that external radiations in the past have had similar possibilities. The most outstanding feature in the geologic history is the periodicity of its eras. On the basis of radioactivity, astronomers allot a period of 1,500,000,000 years to the earth's history. Five times during that period there have been violent outbursts of surface activity followed by drastic changes in the dominant forms of plant and animal life.

The galactic system of which our own solar system is a small part is shaped like a watch crystal, the plane of which is the plane of the Milky Way. The system is thinner at its edge, and bulges somewhat at its center at the position of Sagittarius. Around this center the entire galaxy revolves once in 300,000,000 years. There have been five of these galactic days during the billion and a half years of the earth's existence.

Rhythmic activities are familiar to everyone today. The earth revolves around its axis once in every twenty-four hours, giving us our day and night. It revolves around the sun in a fraction over 365 days, giving us our year and our seasons. Sun spots appear with remarkable regularity, rising to a maximum and receding in twenty-two-year cycles with eleven-year half cycles, and eighty-nine year major cycles. Ultra violet radiations vary with the time of day and, by their activity in ionizing the cosmic rays in the area just above the stratosphere, bring the whole zone of ionization closer to the earth during the night and farther away during the day. Motorists frequently find that their motors run more easily at night and that radio reception is clearer.

Gamma rays are known to abound in all regions of volcanic activity, and since all major geologic eras culminated in widespread volcanic eruptions, periodic increase in gamma ray activity must have accompanied each outburst. The general surface undulations which occurred before and during all mountain formations made certain the widespread dissemination of the rays which now are concentrated in the immediate vicinity of volcanoes.

Development of the Horse

The scene of the progressive adaptation of the horse to speed is generally conceded to be the dry, grassy plains of the American continent.

Eohippus, the "dawn horse" of the lower Eocene, was the earliest type. This horse was but twelve inches high, had a short head and neck, and digitigrade feet, in which the hind foot had three toes touching the ground, and the remnant of the fourth and a splinter of the fifth. The fore feet still retained their usefulness in getting food, since four digits touched the ground. As the ulna and fibula were still retained, rotation of the limbs was possible, and the gait probably resembled that of a dog. The cusps of the molar teeth were fused into crests, but the premolars still had the tearing structure.

Orohippus of the middle Eocene was thirteen and a half inches high; it had lost the splint of the fifth digit on the hind foot, had the outer finger of the forefoot shortened, and the fourth premolar was of grazing structure. *Epihippus* of the upper Eocene showed the first evidence of predominance of the middle finger and had an additional grazing tooth in the third premolar.

During the Oligocene, great advance in height was made, *Mesohippus* of the upper Oligocene being eighteen inches high. There were three digits in both fore and hind feet, a long splint of the fourth still persisting in the hand. All premolars were perfect grazing teeth except the first.

Merychippus of the Miocene had attained a height of forty inches and was functionally one-toed, although still retaining side digits. The teeth were increasing in length and were cement covered.

During the Pliocene Period there were extensive migrations due to the approaching cold of the Pleistocene glaciations. *Pliohippus* was a one-toed horse of the lower Pliocene in which the teeth were intermediate, long-crowned and heavily cemented; in the Pleistocene the genus *Equus* was found for the first time, on the plains of Texas. It was sixty inches high, about the size of a western broncho. It had a large head with very long

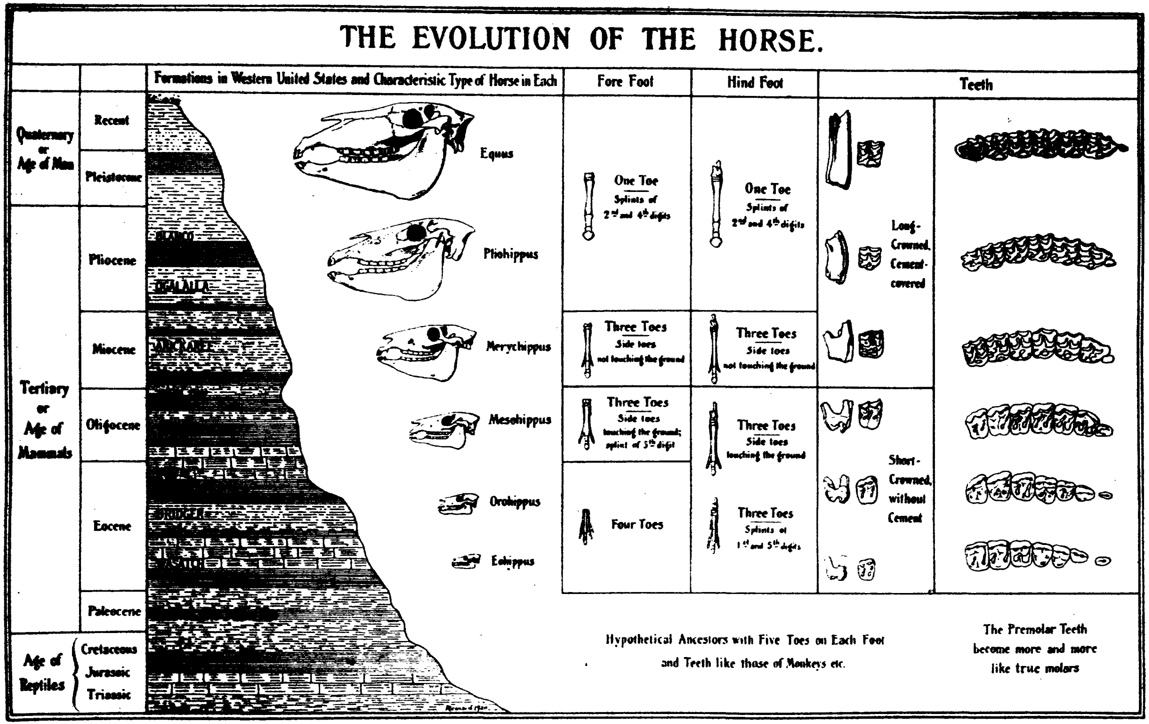

THE EVOLUTION OF THE HORSE.
Formations in Western United States and Characteristic Type of Horse in Each
Fore Foot
Hind Foot
Teeth
Quaternary or Age of Man
Recent
Pleistocene
Tertiary or Age of Mammals
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Age of Reptiles
Cretaceous
Jurassic
Triassic
BLANCO
OGALALLA
ARICKAREE
BRIDGER
WASATCH
Equus
Pliohippus
Merychippus
Mesohippus
Orohippus
Eohippus
One Toe
Splints of 2nd and 4th digits
Three Toes
Side toes not touching the ground
Three Toes
Side toes touching the ground; splint of 5th digit
Four Toes
One Toe
Splints of 2nd and 4th digits
Three Toes
Side toes not touching the ground
Three Toes
Side toes touching the ground
Three Toes
Splints of 1st and 5th digits
Long-Crowned, Cement-covered
Short-Crowned, without Cement
Hypothetical Ancestors with Five Toes on Each Foot and Teeth like those of Monkeys etc.
The Premolar Teeth become more and more like true molars

Fig. 333.—Evolution of the horse. (Photographed by the American Museum of Natural History from group mounted in museum. Courtesy of the American Museum.)

crowned teeth. The cement was covered with enamel. Well-developed splints were found on both the fore and hind feet but there was a tendency to fuse with the cannon bone; the distinctly one-toed type was thus established.

During the Ice Ages of the Pleistocene, horses became extinct in America and all horses native to America today have been imported from Europe. Osborne believed that the elephants migrating from Africa may have brought with them Tsetse flies attached to their hides. These flies, bearing parasites deadly to the horses, may have spread a fatal infection among them.

CHAPTER XXXI

CLASSIFICATION OF ANIMALS

Phylogeny

The phylogenetic tree shown in Fig. 334 is a diagrammatic representation of the relationships of the animal kingdom. It is not to be taken as the last word in relationships, however, as opinions differ on many points, especially on the origin of the vertebrates from the invertebrates. The general diphyletic nature of the tree is, however, widely accepted as representing a fundamental divergence from the parent stem very close to the coelenterate line.

This divergence is based on two characters: the presence or absence of metamerism, and the development of the third germ layer. The latter character is probably a more fundamental one, since the germ layers established the fundamental organization of animals. The segmented series leading to the arthropods is known as the teloblast series, and the unsegmented line, leading to the echinoderms, and possibly to the vertebrates, is the enterocoele series.

In the organisms of the teloblast series the mesoderm is derived from two teloblast cells which appear at the posterior end of the trochophore larva, and from which the mesoderm develops as a solid mass in each segment, later splitting to form the cavities of the coelom.

In the enterocoele series, on the other hand, the mesoderm grows from the region of the digestive tract, typically as a pouch, so that the cavity is present when the germ layer is formed. This method of origin is of interest, for it is also typical of the chordates. Among the prochordates, there is a form, Balanoglossus (Dolichoglossus), in which the embryonic development resembles very closely that of the echinoderms, and in Amphioxus, another prochordate, the development of the archenteric pouches is almost diagrammatic in its simplicity.

In the higher vertebrates there are modifications due to specialized development, but the mesoderm is developed typically from the region of the digestive tract. The metamerism of vertebrates is often considered a stumbling block to this theory of vertebrate origin, but vertebrate metamerism is internal only, and so very specialized that it is possible it was initiated by the vertebrates in the course of their early development.

In considering the origin of any group it is not in the modern forms that one expects to find the transitional characters, since the groups as we know them today were established in the early prehistoric ages. The invertebrates had completed their development before the known fossil history began, and the vertebrates appeared as early as the Silurian, so that in the Silurian deposits lies buried the story of the origin of the vertebrates from the invertebrates.

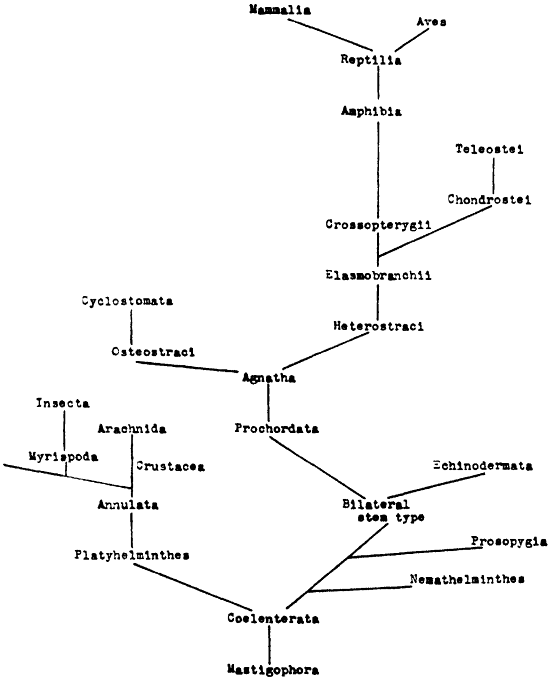


Fig. 331.—Diagram to represent the probable relationships of the animal groups.

Paleontologists now recognize the grovelling type as primitive in the early vertebrate groups, as food was more plentiful close to shore where the invertebrates abounded. The earliest known vertebrate fossils are the jawless grovelling ostracoderms. The structure of these interesting armored fishes has been worked out in detail by two Swedish palentologists, Stensio and Kiaer. They have demonstrated the existence of true bone cells in the armor and have worked out enough of the internal anatomy to show that the ostracoderms, through one group, are related to the modern cyclostomes, or the jawless lamprey eels, and through another group, to the elasmobranch fishes, or the sharks and the rays. Thus bone development preceded the development of cartilage, and the internal skeleton has been a secondary feature in the development of the vertebrates.

Theories regarding the relationship of the vertebrates to invertebrate groups tend to point to three possible stem groups: the annelids, the arthropods, especially the scorpions, and the echinoderms.

The annelid theory of Dohrn is based on the presence of metamerism and the resemblance of the excretory nephridia in the annelids to the kidneys of vertebrates. The history of metamerism, outlined in Chapter XXVI, shows that metameric development appeared first internally, cut through to the outside, and finally disappeared internally, leaving a segmented outer chitinous casing. Vertebrate metamerism is internal exclusively, and homology with externally segmented forms is impossible. Moreover, it was necessary for proponents of this theory to turn the annelid upside down in order to make any analogy with the nervous system.

This disposes of Patten's arthropod theory also. In fact, the resemblance of the bony armor of the ostracoderm carapace to the horny carapace of the Silurian scorpions may easily be a parallel development. These early scorpions far out-stripped the prochordates both in size and voracity, and Romer has suggested that the vertebrates developed their armor as a protection against these very eurypterids.

In modern animals, specializations have in many cases covered over the primitive characters on which the history of animal development depends, and it is in embryologic development that one may expect to find the clearest picture of the ancestral history, for while embryologic development also shows adaptations to environmental change, especially in those forms in which the eggs are not laid in the water, the general trend of development is still closely paralleled in related forms.

On this basis, therefore, the echinoderm theory offers the most convincing evidence for the origin of the vertebrates on the basis of the origin of the mesoderm from the region of the archenteron. This is a characteristic of the enterocoele series, and is completely lacking in the teloblast series.

The early development of the Ostracoderms is unknown and will doubtless remain so, since only the heavy armor of the adult exoskeleton has made its preservation possible. External armor of some kind was common in all the invertebrate groups. In none of them, however, was there anything paralleling the bony structure of the Osteostraci or the denticles of the Heterostraci. The armor, therefore, in spite of its superficial resemblance to the carapace of the Trilobites and early scorpions, fails to show any homologies of structure.

Nor does the jawless Ostracoderm with its external armor preclude the existence of elongate, soft-bodied ancestors of the Balanoglossus (Dolichoglossus) type. The resemblance of the Tornaria larva to the Bipinnaria with the parallel development of the mesoderm from archenteric pouches thus remains the most convincing evidence for the origin of the vertebrates from the invertebrates.

Thus the first attempt toward higher development probably showed itself in those soft-bodied prochordate forms that had stiffened notochords, gill slits, and dorsal nerve cords, but, which for purposes of protection while gathering food, took to the sessile or the burrowing habit. The known modern types are probably quite highly specialized and even degenerate representatives of the hypothetic Silurian types, whose lack of bone formation, or of external armor, precluded the formation of any permanent fossil record.

The armored jawless types then represent the next move toward freer habitat and more venturesome life, the heavy armor serving as protection against the more active of the invertebrate enemies. Thus protected, fishes gradually ventured farther into the sea, and in the late Silurian and early Devonian, pelagic fishes put in their appearance, losing parts of the armor as they adopted deeper water habitats, and eventually developing the internal cartilaginous skeleton, which became the foundation for the bony endoskeleton of the established vertebrate groups. Since bone is especially resistant to destruction by time, the history of the bony vertebrates has been left as an exceptionally complete record in the deposits of succeeding geologic ages.

CLASSIFICATION

Note.—Except for a few stem groups important in establishing relationships, no strictly fossil orders are included. In the Aves, because of the large number of types mentioned, no scientific names are used.

ANIMAL KINGDOM

- Phylum **Protozoa**— Animals with unicellular organization
  - Subphylum **Mastigophora**—Locomotion by flagella
    - Euglena—nutrition heterotrophic
    - Volvox—spherical colony
    - Peranema—no chromatophores nutrition saprozoic
  - Subphylum **Sarcodina**—Locomotion by pseudopodia
    - Class ACTINOPODA— Pseudopodia raylike, supported by axial threads
      - Actinophrys
    - Class RHIZOPODA— Pseudopodia not supported by axial threads
      - Amoeba—naked
      - Arcella—chitinous shell
      - Difflugia—shell of sand grains
  - Subphylum **Infusoria**—Locomotion by cilia
    - Class CILIATA— Cilia during adult stage
      - Paramecium
      - Vorticella—stalked, and often colonial
    - Class SUCTORIA— No cilia in adult stage
      Tubelike tentacles
      - Acineta
  - Subphylum **Sporozoa**—No locomotor organelles
    Spore formation
    - Class TELOSPORIDIA— Spore formation occurs but once
      - Gregarina (intestinal parasite)
      - Plasmodium (blood parasite)

- **Class NEOSPORIDIA**— Frequent spore formation
    - Nosema (parasite on insects)
- Phylum **Porifera** (sponges)—
    - **Radial symmetry**
    - **Two germ layers**; ectoderm lining gastral canals
    - **Collar cells**
    - Class CALCAREA— Spicules of calcium carbonate
        - Leucosolenia—gastral layer continuous
        - Grantia—gastral layer limited to flagellated chambers
    - Class HEXACTINELLIDA— Spicules of silicon
        - Euplectella (Venus flower basket)
    - Class DEMOSPONGIA— Skeleton of spongin, with or without spicules of silicon
        - Euspongia (bath sponge) without spicules
- Phylum **Coelenterata** (jellyfishes and corals)—
    - **Radial symmetry**
    - **Two germ layers**; endoderm lining digestive tract
    - No coelom or anus
    - Class HYDROZOA— Polyp and medusa stages
        - Polymorphism
            - Hydra—polyp, no medusa
            - Obelia—polyp and free medusa
            - Gonionemus—medusa and reduced polyp
            - Physalia (Portuguese man-of-war)—floating colony with extreme polymorphism
    - Class SCYPHOZOA— Medusa forms
        - Reduced alternation
            - Aurelia
    - Class ANTHOZOA— Polyps only
        - No alternation
        - **Subclass ZOANTHARIA**— Tentacles and mesenteries in multiples of 5 or 6
            - Two siphonoglyphs
                - Metridium (sea anemone)—solitary polyp
                - Edwardsia—8 primary mesenteries only—primitive form
                - Madrepora (reef coral)—colonial

Subclass ALCYONARIA—Tentacles and mesenteries 8
One siphonoglyph
Alcyonium
Corallium (precious coral)
Tubipora (organ-pipe coral)
Gorgonia (sea fan)—horny axis
Pennatula (sea pen)

Class CTENOPHORA (comb jellies)—
Transparent, free swimming
Forms of doubtful affiliations
Pleurobrachia

TELOBLAST SERIES

Phylum **Platyhelminthes** (flatworms)—
Bilateral symmetry
Three germ layers
Mouth ventral; no anus or coelom

Class TURBELLARIA— Digestive cavity fully developed
Planaria

Class TREMATODA— Digestive apparatus reduced
Parasitic, with alternation of generations
Distomum (liver fluke)

Class CESTODA— No digestive cavity, parasitic
Pseudoalternation of generations
Taenia (tapeworm)

Phylum **Nemertinea**— Nonparasitic, unsegmented flatworms
Blood vascular system
Anus present but coelom absent
Cerebratulus

Phylum **Trochelminthes** (rotifers)—
Adult resembles trochophore larva of Annelids
Position uncertain
Hydatina

Phylum **Annulata** (segmented worms)—
Elongate, segmented with systems well developed and organs serially repeated
Anus and coelom present
Larva typically a trochophore

Class ARCHIANNELIDA— Segmentation faintly marked externally but complete internally
Marine worms without parapodia or setae

Larva a trochophore
Dinophilus—segmentation marked externally by bands of cilia
Polygordius

Class CHAETOPODA— Segmentation complete internally and externally
Organs of locomotion on each segment
Respiratory organs, when present, external

ORDER POLYCHAETA— Marine forms, parapodia, trochophore larva

Suborder ERRANTIA— Free swimming forms
Nereis

Suborder SEDENTARIA— Tube dwelling or burrowing worms
Chaetopterus

ORDER OLIGOCHAETA— Terrestrial burrowing forms
No parapodia but setae present
No trochophore larva
Lumbricus (terrestrial form)

Class HIRUDINEA (leeches)—
External and internal segmentation do not agree
Coelom limited
No organs of locomotion
Vascular system a hemocoele
Hirudo

Class GEPHYREA— Position uncertain but larva a trochophore
Segmentation absent in adult
No parapodia
Setae few in number
Coelom extensive
No ganglia on nerve cord
Phascolosoma—U-shaped digestive tract
Trochophore not typical but development of Annelid type
Bonellia—sexual dimorphism, microscopic male lives in nephridium of female

Phylum **Mollusca—** Larva a modified trochophore
Perivisceral coelom and hemocoele
Parapodia absent

Body divided into cephalic, mantle, and foot regions
Shell secreted by mantle
Blood vascular system and respiratory systems coordinated

Class AMPHINEURA— Elongate, symmetrical
Mouth and anus at opposite ends
Shell of several plates
Chiton

Class GASTROPODA (snails)—
Asymmetrical with spirally coiled univalve shell
Head well developed
Radula present
Trochus (pointed spire)
Busycon
Helix (land snail)

Class SCAPHOPODA— Elongate body, foot, and shell
Respiration through mantle
Dentalium

Class PELECYPODA— Laterally compressed body
Bilobed mantle secretes bivalved shell
Foot plowshare
Gills lamellate
Venus (marine hard-shelled clam)—two adductor muscles, completely lamellate gills
Unio (fresh water clam)
Ostrea (oyster)—1 adductor muscle; foot lost
Pecten (scallop)—1 adductor muscle
Gill not completely lamellate
Teredo (shipworm)—elongate, boring

Class CEPHALOPODA— Bilateral and symmetrical
Foot modified into head appendages and siphon
Eyes and brain well developed
Nautilus, large, external, chambered shell
Loligo (squid)—10 arms; 2 long, 8 short
Octopus (devilfish)—8 arms of equal length

- Phylum **Arthropoda**—
  - Segmentation specialized into head, thorax, and abdomen
  - Appendages jointed
  - Exoskeleton chitinous
  - Heart tubular and ostiated
  - Coelom a hemocoele
  - Muscles striated
  - Cephalization advanced
  - Subphylum **Branchiata**—Chiefly aquatic, breathing by gills
    - Class CRUSTACEA—
      - Heavy exoskeleton
      - Appendages typically biramous
      - Head of 5 segments
      - Nauplius larva
      - Subclass ENTOMOSTRACA—
        - Segments variable
        - Excretory organs are shell glands on second maxillae
          - Apus—Abdominal appendages present
          - Branchipus—Abdominal appendages absent
          - Cypris—laterally compressed in bivalve shell
          - Lepas (goose barnacle)—bivalve shell of 5 calcareous plates
          - Balanus (rock barnacle) shell of 6 plates
          - Sacculina—parasite on crab (Brachyura) adult metamorphoses into chitinous ring with roots branching throughout host. No appendages
      - Subclass MALACOSTRACA—
        - Head segments 5, thoracic 8, abdominal 6 and telson
        - Appendages on all regions
        - One pair of eyes
        - Excretory organs are green glands on antennae
          - Homarus (lobster)
          - Penaeus (shrimp)
          - Cancer (crab)
          - Cambarus (crayfish)

Subphylum **Tracheata**—	Tubular tracheae Appendages uniramous Embryonic membranes and salivary glands
CLASS ONYCHOPHORA—	Terrestrial wormlike forms Thin cuticle, continuous muscular wall without joints One pair of jaws Peripatus
CLASS MYRIAPODA—	Thorax and abdomen not separate Appendages on every segment but last
Order Chilopoda—	One pair appendages to each segment Scolopendra (centipede)
Order Diplopoda—	Two pairs appendages to each segment Julus (millipede)
Class INSECTA (Hexapoda)—	Three pairs thoracic appendages No abdominal appendages Wings on thorax, if present Metamorphosis
(Condensed classification)	
Order *Aptera*—	Without wings No metamorphosis Lepisma (silver moth)
Order *Pseudoneuroptera*—	Membranous wings Incomplete metamorphosis Libellula (dragon fly)
Order *Orthoptera*—	Straight wings Gradual metamorphosis Rhomaelia (grasshopper)
Order *Hemiptera*—	Triangular wings Incomplete metamorphosis Aphis
Order *Neuroptera*—	Membranous wings Complete metamorphosis Corydalis (Dobson fly)
Order *Lepidoptera*—	Scaly wings Complete metamorphosis Papilio (swallow-tailed butterfly) Actias (luna moth)

Order *Diptera*—	One pair of wings only Complete metamorphosis Musca (house fly) Culex (mosquito)
Order *Coleoptera*—	Outer wings hard Complete metamorphosis Scarabeus (sacred beetle of Egypt)
Order *Hymenoptera*—	Wings for aerial mating Complete metamorphosis Formica (ant) Apis (honeybee)

Class ARACHNIDA (spiders)—

- Head and thorax fused
- Two pairs of jaws; chelicerae and pedipalps
- Four pairs thoracic appendages, all walking legs
- Embryonic membranes and salivary glands
- Respiration by tracheae or book lungs
  - Scorpio (scorpion)
  - Phalangium (daddy longlegs)
  - Epeira (true spider)
  - Nymphon (water spider)
  - Tyroglyphys (mite)
  - Limulus (king crab)

ENTEROCOELE SERIES

Phylum **Nemathelminthes** (roundworms)—

Class NEMATODA—

- Intestine present
- Proboscis absent
  - Ascaris (intestinal parasite)
  - Trichinella (muscle parasite)
  - Necator (human hookworm)

Class ACANTHOCEPHALA—

- Intestine absent
- Proboscis present
  - Echinorhynchus (intestinal parasite)

Phylum **Chaetognatha** (arrow-shaped worms)—

- Body divided into head, trunk, and tail by transverse partitions
- Coelom developed from endoderm of archenteron
  - **Sagitta**

Phylum **Prosopygia**— Body divided into regions
Coelom developed as schizocoele in regions of endoderm developed from archenteron
Lophophore (circlet of tentacles) present
U-shaped digestive tract

Class BRYOZOA (moss animals)—
Colonial
Larva resembles trochophore in some cases
Bugula

Class BRACHIOPODA (lamp shells)—
Bivalve shells dorsoventral
Lingula

Phylum **Echinodermata**— Bilateral larva and adult with secondary radial symmetry
Calcareous spiny exoskeleton
Water vascular system and perivisceral coelom develop as pouches from the archenteron

Class ASTEROIDEA (starfishes)—
Star-shaped, rays not sharply marked off
Coelom continued into rays.
Asterias (starfish)

Class OPHIUROIDEA (brittle stars)—
Star-shaped, rays sharply marked off
Coelom not continued into rays
Ophioglypha (brittle star)
Asterophyton (basket star)

Class ECHINOIDEA (sea urchins)—
Globular or heart-shaped
Alternating ambulacral and interambulacral zones
Arbacia (sea urchin)
Clypeaster (sand dollar)
Spatangus (heart urchin)

Class HOLOTHUROIDEA (sea cucumbers)—
Elongate and Bilateral
Scattered spines
Respiratory trees
Thyone (sea cucumber)

Class CRINOIDEA (sea lilies)—
Stalked
Pentacrinus—stalked permanently
Antedon—adult free

Erratum

On page 595, insert following Subphylum **Hemichordata** and preceding Class AGNATHA:

Subphylum **Vertebrata** (Animals with a spinal column)—

Phylum **Chordata—**
- Notochord
- Gill slits in pharynx
- Hollow, dorsal nerve cord
- Coelom an enterocoele

Subphylum **Cephalochordata** (Fishlike)—
- Notochord the length of the body
- Full-length nerve cord without cranium
- Metapleural folds
  - Amphioxus (lancelet)

Subphylum **Urochordata** (Tunicates)—
- Sessile forms encased in tunic
- Notochord in larva only
- Gill slits numerous
  - Ascidia (sea squirt)

Subphylum **Hemichordata** (Acorn worms)—
- Wormlike with head, trunk, and tail regions
- Notochord in head region only
  - Balanoglossus (Dolichoglossus)

Class AGNATHA—Aquatic forms without jaws or true limbs

Order OSTEOSTRACI (Silurian-Devonian)—
- Armor of one piece with true bone cells
- Gills numerous (9-15), each with a separate opening
- Single dorsal nasal opening
- Two semicircular canals
  - Cephalaspis

Order HETEROSTRACI (Silurian-Devonian)—
- Armor of separate pieces or minute denticles; no bone cells
- Gills not numerous (6-7) with a single opening on each side
- Two nasal sacs
  - Poraspis (shield of five plates)
  - Thelodus (minute denticles)

ORDER CYCLOSTOMATA—
- No armor, cartilaginous endoskeleton
- Gill pouches, each with separate external opening
- Single dorsal nasal opening
- 1 or 2 semicircular canals
  - Petromyzon (lamprey)

Class PLACODERMI, archaic jawed fishes (Devonian)—
Order ARTHRODIRA— Whole body encased in armor
Dinichthys
Order ACANTHODEI (Devonian)—
Fishlike with spines
Climatius

Class CHONDRICHTHYES (Sharklike fishes)—
Body covered with denticles (placoid scales)
Cartilaginous endoskeleton, movable jaws
Gills typically 5 each with separate opening
Two nasal openings
Three semicircular canals
Typical paired appendages; fins, lobe-like
Subclass PLAGIOSTOMI (Sharks and rays)
Order ANTACEA (Sharks)—
Lateral gill openings
Squalus (dogfish)
Carcharias (sand shark)
Order PLATOSOMIA (Rays)—
Ventral gill openings
Raja (common ray)
Torpedo (electric ray)
Subclass HOLOCEPHALI (Chimaeras)—
Dermal denticles few in number
Gills with one external opening
Chimaera

Class OSTEICHTHYES (Bony fishes)—
Subclass ACTINOPTERYGII (Ray-finned fishes)—
Order CHONDROSTEI—
Ganoid scales
Cartilage retained in endoskeleton
Acipenser (sturgeon)
Polypterus
Order HOLOSTEI— Ganoid scale
Bony endoskeleton
Lepidosteus (garfish)
Amia (bowfins)
Order TELEOSTEI (True bony fishes)—
Clupea (herring)
Scomber (mackerel)
Anguilla (eel)
Hippocampus (Sea horse)
Salmo (salmon and trout)

- Subclass CROSSOPTERYGII (Lobe-finned fishes)—
    - Osteolepis (Devonian)
    - Coelacanthus (modern)
- Subclass DIPNOI (Lung fishes)—Protopterus (African lungfish)

Class AMPHIBIA—
- Semi-adapted to terrestrial life
- Terrestrial appendages
- Order URODELA (Salamanders and newts)—
    - Necturus (mudpuppy)
    - Amblystoma (tiger salamander)
- Order ANURA (Frogs and Toads)—
    - Rana (grass frog)
    - Bufo (toad)
    - Hyla (tree toad)
- Order APODA (limbless)— Ichthyophis

Class REPTILIA—
- Subclass ANAPSIDA—
    - Order CHELONIA (Turtles and tortoises)—
        - Testudo (tortoise)
        - Chelone (green turtle)
        - Chelydra (snapping turtle)
- Subclass LEPIDOSAURIA—
    - Order RHYNCHOCEPHALIA— Sphenodon
    - Order SQUAMATA (Lizards and Snakes)—
        - Suborder LACERTILIA (Lizards)—
            - Varanus (monitor lizard)
            - Heloderma (gila monster)
            - Chameleo (chameleon)
        - Suborder OPHIDIA (Snakes)—
            - Crotalus (rattle-snake)
            - Agkistrodon (copperhead)
            - Python
- Subclass ARCHOSAURIA (ruling reptiles)—
    - Includes dinosaurs
    - Order CROCODILIA (only modern order)—
        - Crocodilus
        - Alligator
        - Gavialis

Class AVES—
- Subclass ARCHAEORNITHES (Archaic birds; Jurassic)—
    - Teeth on jaws
    - Claws on wings
        - Archaeopteryx
        - Archaeornis

Sublcass Neornithes (Modern birds)—
Toothless beaks
Wing digits rudimentary

Division A—Ratitae (Running birds)—
(Kiwi, ostrich, emu, rhea)

Division B—Carinatae (Keeled flying birds)—

Order Gaviiformes—	Loons
Order Colymbiformes—	Grebes
Order Procellariiformes—	Albatrosses, petrels
Order Pelecaniformes—	Pelicans, cormorants, boobies
Order Ciconiiformes—	Herons, bitterns, ibises, spoonbills, flamingos
Order Anseriformes—	Swans, ducks, geese
Order Falconiformes—	Vultures, eagles, hawks, falcons
Order Galliformes—	Grouse, quail, pheasants, turkeys
Order Gruiformes—	Cranes, rails, coots, gallinules, limpkins
Order Charadriiformes—	Oyster catchers, plovers, curlews, snipes, sandpipers, avocets, phalaropes, jaegers, gulls, terns, skimmers, auks, murres, puffins
Order Columbiformes—	Pigeons, doves
Order Cuculiformes—	Cuckoos
Order Psittaciformes—	Parrots
Order Strigiformes—	Owls
Order Caprimulgiformes—	Nighthawks, whippoorwills
Order Micropodiformes—	Swifts, hummingbirds
Order Trogoniformes—	Trogons
Order Coraciiformes—	Kingfishers, rollers
Order Piciformes—	Woodpeckers
Order Passeriformes—	Perching birds
Family Cotingidae—	Cotingas
Family Tyrranidae—	Flycatchers
Family Aludidae—	Larks
Family Hirundinidae—	Swallows
Family Corvidae—	Crows, jays, magpies
Family Paridae—	Titmice
Family Sittidae—	Nuthatches
Family Certhiidae—	Creepers
Family Chamaeidae—	Wren-tits
Family Cinclidae—	Dippers
Family Troglodytidae—	Wrens
Family Mimidae—	Mockingbird, catbird, thrasher
Family Turdidae—	Thrushes, robins, bluebirds
Family Sylviidae—	Kinglets, warblers
Family Motacillidae—	Pipits, wagtails

- Family BOMBYCILLIDAE— Waxwings
- Family PTILOGONATIDAE— Silky flycatchers
- Family LANIIDAE— Shrikes
- Family SATURNIDAE— Starlinks
- Family VIREONIDAE— Vireos
- Family COEREBIDAE— Honey creepers
- Wood warblers
- Family PLOCEIDAE— English sparrow
- Family ICTERIDAE— Blackbirds, orioles
- Family THRAUPIDAE— Tanagers
- Family FRINGILLIDAE— Sparrows, grosbeaks, finches

Class MAMMALIA—
- Subclass PROTOTHERIA (Egg-laying mammals)—
  - Ornithorhynchus (duckbill)
  - Echidna (spiny anteater)
- Subclass METATHERIA—Placenta not fully developed
  - Order MARSUPIALIA (Pouched mammals)—
    - Didelphys (opossum)
    - Macropus (kangaroo)
- Sublcass EUTHERIA (Placental mammals)—
  - Order INSECTIVORA (Insect eating, plantigrade)—
    - Sorex (shrew)
    - Tupaia (tree shrew)
    - Talpa (mole)
  - Order CARNIVORA (Flesh eating, digitigrade)—
    - Suborder FISSIPEDIA (Terrestrial)—
      - Family VIVERRIDAE— Herpestes (monogoose)
      - Family HYAENIDAE— Hyaena
      - Family FELIDAE— Felis (all cats)
      - Family MUSTELIDAE— Martis (martin)
      - Family CANIDAE— Canis (dogs, wolves)
      - Family PROCYONIDAE— Ailurus (panda)
      - Family URSIDAE— Ursus (bears)
    - Suborder PINNIPEDIA (Aquatic—at home on land)—
      - Family OTARIIDAE— Callorhinus (fur seal)
      - Family ODOBAENIDAE— Odobaenus (walrus)
  - Order PERISSODACTYLA (Odd-toed ungulates)—
    - Family EQUIDAE— Equus (horse)
    - Family TAPIRIDAE— Tapirus (tapir)
    - Family RHINOCEROTIDAE—Rhinoceros
  - Order ARTIODACTYLA (Even-toed ungulates)—
    - Suborder SUINA (Piglike)—Sus (pigs)
      - Hippopotamus
    - Suborder TYLOPODA (Desert types)—
      - Camelus (camel)
      - Auchenia (llama)

- Suborder PECORA (Ruminants)—
  - Cervus (red deer)
  - Rangifer (reindeer)
  - Giraffa
  - Okapia (okapi)
  - Bos (cattle)
  - Ovis (sheep)
  - Capra (goats)
- Order HYRACOIDEA— Hyrax (cony)
- Order PROBOSCIDEA— Elephas (Asiatic elephant)
  - Loxodonta (African elephant)
- Order SIRENIA— Halicore (dugong)
  - Manatus (manatee)
- Order RODENTIA (Gnawing mammals)—
  - Suborder SIMPLICIDENTATA (One pair upper incisors)—
    - Castor (beaver)
    - Mus (mouse)
    - Rattus (rat)
    - Cavia (guinea pig)
  - Suborder DUPLICIDENTATA (Two pairs upper incisors)—
    - Lepus (hares)
    - Oryctolagus (rabbits)
- Order CHIROPTERA (Flying mammals)—
  - Vespertilio (common bat)
- Order CETACEA (Aquatic, not at home on land)—
  - Front limbs retained as flippers
  - Hind limbs mere rudiments
  - Suborder ODONTOCETI (Toothed whales)—
    - Physeter (sperm whale)
    - Phocaena (porpoise)
  - Suborder MYSTACOCETI (Whalebone whales)—
    - Balaena (right whale)
- Order EDENTATA (Teeth absent or degenerate)—
  - Suborder LORICATA (Armored forms)—
    - Dasypus (armadillo)
  - Suborder PILOSA (Hairy forms)—
    - Myrmecophaga (giant anteater)
    - Choloepus (tree sloth)
- Order TUBULIDENTATE (Tubelike snout)—
  - Peglike teeth, powerful claws
  - Orycteropus (aard vark)
- Order PHOLIDOTA (Scales)— Manis (Pangolin)

Order PRIMATES (Grasping limbs, plantigrade)—
- Suborder LEMUROIDEA (Placental connections distributed)—
  - Not shed at birth
  - Eyes lateral
    - Lemur (common lemurs)
    - Galago (bush baby)
    - Loris (slow lemur)
- Suborder TARSIOIDEA (Placenta shed at birth)—
  - Hopping movements
  - Eyes turned forward, stereoscopic vision
    - Tarsius
- Suborder ANTHROPOIDEA (Placenta shed at birth)—
  - Eyes forward, fovea centralis on retina focuses detail of stereoscopic vision
  - Infraorder PLATYRRHINI (South American monkeys)—
    - Flat nosed, nostrils widely separated, open sidewise
    - 3 premolars in each half jaw
    - Long tail
      - Cebus (organ-grinder's monkey), prehensile tail
      - Hapale (marmoset)
  - Infraorder CATTARRHINI (Old world forms)—
    - Nostrils close together, open forward or down
    - 2 premolars in each half jaw
    - Tail short or absent
    - Thumb and (except in man) big toe opposable
    - Brain large, face naked, hairy covering thin
    - Family CERCOPITHECIDAE (Old World monkeys)—
      - Macacus (rhesus monkey)
      - Papio (baboon)
    - Family SIMIIDAE (Great apes)—
      - Hylobates (gibbon)
      - Simia (orang)
      - Gorilla
      - Anthropopithecus (chimpanzee)
    - Family HOMIIDAE— Homo (man)

REFERENCES

1. Arber, Agnes: Herbals: Their Origin and Evolution, London and New York, Cambridge University Press, 1938
2. Babcock, E. B., and Clausen, R. E.: Genetics in Relation to Agriculture, ed. 2, New York, McGraw-Hill Book Company, 1927.
3. Bayliss, W. M.: General Physiology, ed. 3, New York, Longmans, Green and Company, 1923.
4. —: Introduction to General Physiology, New York, Longmans, Green and Company, 1919.
5. Beaver, Wm. C.: Fundamentals of Biology, ed. 2, St. Louis, The C. V. Mosby Company, 1940.
6. Borrodaile, A. A.: Elementary Zoology, New York, Oxford University Press, 1924.
7. Bower, F. O.: The Origin of a Land Flora, New York, The Macmillan Company, 1908.
8. Bower, F. O.: Primitive Land Plants, New York, The Macmillan Company, 1935.
9. Britton, N. L., and Brown, A.: Illustrated Flora of the Northern States and Canada, New York, Charles Scribner's Sons, 1897.
10. Brown, W. H.: The Plant Kingdom, Boston, Ginn and Company, 1935.
11. Calkins, G. N.: Protozoology, Philadelphia, Lea and Febiger, 1909.
12. —: Biology of the Protozoa, Philadelphia, Lea and Febiger, 1926.
13. Cameron, A. T.: Recent Advances in Endocrinology, Philadelphia, P. Blakiston's Son and Company, 1935.
14. Campbell, D. H.: Mosses and Ferns, ed. 3, New York, The Macmillan Company, 1928.
15. Castle, W. E.: Genetics and Eugenics, ed. 3, Cambridge, Mass., Harvard University Press, 1924.
16. Chamberlain, C. J.: Gymnosperms—Structure and Evolution, Chicago, University of Chicago Press, 1935.
17. Child, M. C.: Physiological Foundations of Behavior, New York, Henry Holt and Company, 1924.
18. —: Senescence and Rejuvenescence, Chicago, University Chicago Press, 1925.
19. Clements, F. E., and Clements, E. S.: Flower Families and Ancestors, New York, H. W. Wilson Company, 1928.
20. Coulter, J. M., and Chamberlain, C. J.: Morphology of Gymnosperms, Chicago, University of Chicago Press, 1917.
21. Cowdry, C. V., and others: Special Cytology, New York, Paul B. Hoeber, 1928.
22. —, and —: General Cytology, Chicago, University Chicago Press, 1925.
23. Dahlgren, U.: Origin of Electricity in Animals, American Naturalist, pp. 193-202, 1910.
24. The Production of Light by Animals, Philadelphia, J. Franklin Inst., 1916.
25. —, and Kepner, W. A.: Principles of Animal Histology, New York, The Macmillan Company, 1908.
26. Darwin, Charles: The Origin of Species, Am. ed. New York, D. Appleton and Company, 1859.
27. —: The Formation of Vegetable Mould Through the Action of Worms, Am. ed., New York, D. Appleton and Company, 1888.
28. Dobell, Clifford, F. R. S.: Leeuwenhoek and His Little Animals, New York, Harcourt, Brace and Company, 1924.
29. Eames, A. J., and MacDaniels, L.: An Introduction to Plant Anatomy, New York, McGraw-Hill Book Company, 1925.

30. Elton, Charles: Animal Ecology, New York, The Macmillan Company, 1927.
31. Frobisher, Martin Jr.: Fundamentals of Bacteriology, Philadelphia, W. B. Saunders Company, 1944.
32. Giltner, W.: General Microbiology, Philadelphia, P. Blakiston's Son and Company, 1928.
33. Haliburton, W. D., and McDowall, R. J. S.: Handbook of Physiology, ed. 34, Philadelphia, P. Blakiston's Son and Company, 1935.
34. Harvey, R. B.: Plant Physiological Chemistry, New York, The Century Company, 1930.
35. Hegner, R. W.: College Zoology, ed. 5, New York, The Macmillan Company, 1943.
36. —, and Taliaferro, W. H.: Human Protozoology, New York, The Macmillan Company, 1925.
37. Henderson, I. F., and Henderson, W. D.: A Dictionary of Scientific Terms, New York, D. Van Nostrand Company, Inc., 1929.
38. Henrici, A. T.: The Biology of Bacteria, ed. 2, Boston, D. C. Heath & Company, 1939.
39. Holman, R. M., and Robbins, W. W.: Textbook of General Botany, ed. 3, New York, John Wiley and Sons, 1938.
40. Holmes, S. J.: The Biology of the Frog, ed. 4, New York, The Macmillan Company, 1927.
41. Hurst, C. C.: The Mechanism of Creative Evolution, Cambridge, The University Press, 1932.
42. Hutchinson, J.: The Families of Flowering Plants. Vol. I. Monocotyledons, London, The Macmillan Company, 1926; Vol. II. Dicotyledons, 1934.
43. Hyman, L.: Laboratory Manual for Elementary Zoology, Chicago, University Chicago Press, 1919.
44. —: A Laboratory Guide for Comparative Vertebrate Anatomy, Chicago, University Chicago Press, 1922.
45. Jackson, B. D.: A Glossary of Botanic Terms, Philadelphia, J. B. Lippincott Company, 1928.
46. Jeffrey, E. C.: The Anatomy of Woody Plants, Chicago, University of Chicago Press, 1917.
47. Jennings, H. S.: Behavior of the Lower Organisms, New York, Columbia University Press, 1906.
48. Jensen, Boysen: Growth Hormones in Plants. Translated and Revised by Avery and Burkholder, New York, McGraw-Hill Book Company, 1936.
49. Kent, W. S.: A Manual of the Infusoria, London, 1880-1882.
50. Knowlton, F. H.: Plants of the Past, Princeton University Press, 1927.
51. Lane, H. H.: Animal Biology, Philadelphia, P. Blakiston's Son and Company, 1929.
52. Lang, Arnold: Comparative Anatomy of the Invertebrates, London.
53. Lankester, E. R.: A Treatise on Zoology, London, Black, 1900-1909.
54. Lillie, F. R.: The Freemartin: A Study of the Action of Sex Hormones in the Foetal Life of Cattle, J. Exper. Zool. **23**: 371-452, 1917.
55. —: Problems of Fertilization, Chicago, University Chicago Press, 1919.
56. Locy, W. A.: Growth of Biology, New York, Henry Holt and Company, 1925.
57. Loeb, Jacques: Artificial Parthenogenesis and Fertilization, Chicago, University Chicago Press, 1913.
58. Lull, A. S.: Organic Evolution, revised, New York, The Macmillan Company, 1929.
59. McBride, E. W.: Invertebrata—In Textbook of Embryology. Vol. I, New York, The Macmillan Company, 1914.

60. McDougal, W. B.: Plant Ecology, Philadelphia, Lea and Febiger, 1931.
61. Marsland, D., and Plunkett, C. R.: Principles of Modern Biology, New York, Henry Holt and Co., 1945.
62. Mast, S. O.: The Reactions of Didinium Nasutum with Special Reference to the Feeding Habits and the Function of Trichocysts, Biol. Bull. **16:** 1909.
63. Miller, E. C.: Plant Physiology, New York, McGraw-Hill Book Company, 1931.
64. Minchin, E. A.: Introduction to the Study of the Protozoa, London, 1912.
65. Mitchell, P. H.: A Textbook of General Physiology, ed. 2, New York, McGraw-Hill Book Co., 1932.
66. Morgan, T. H.: The Theory of the Gene, New Haven, Yale University Press, 1926.
67. Morse, A. P.: Researches in North American Acrididae, Carnegie Publication, No. 18, 1904.
68. —: Further Researches in North American Acrididae, Carnegie Publication, No. 68.
69. Muller, H. J.: Artificial Transmutation of the Gene, Science **66:** 84, 1927.
70. Newman, H. H.: The Biology of Twins, Chicago, University Chicago Press, 1917.
71. —: Vertebrate Zoology, New York, The Macmillan Company, 1920.
72. —: The Physiology of Twinning, Chicago, University Chicago Press, 1923.
73. —: Readings in Evolution, Genetics, and Eugenics, Chicago, University Chicago Press, 1925.
74. —, and others: Nature of the World and Man, ed. 2, Chicago, University Chicago Press, 1927.
75. Nordenskiöld, Erik: The History of Biology: A Survey, New York, Alfred A. Knopf, 1928.
76. Osborn, H. F.: From the Greeks to Darwin, New York, The Macmillan Company, 1894.
77. Painter, T. S.: A Comparison of the Rat and Mouse with Reference to the Question of Chromosome Homology in Animals, Genetics **13:** 180, 1928.
78. —, and Muller, H. J.: Parallel Cytology and Genetics of Induced Translocations and Deletions in Drosophila, J. Hered. **20:** 287, 1929.
79. Parker, T. J., and Haswell, W. A.: Textbook of Zoology (2 vol.), ed. 4, New York, The Macmillan Company, 1928.
80. Peattie, D. C.: Green Laurels, New York, The Literary Guild, 1936.
81. Pool, R. J.: Flowers and Flowering Plants, New York, McGraw-Hill Book Company, 1929.
82. Radcliffe, L.: Artificial Pearl Culture, Science (News Service), 1928.
83. Reynolds, S. H.: The Vertebrate Skeleton, New York, G. P. Putnam's Sons, 1913.
84. Russell, B. A. W.: ABC of Atoms, New York, E. P. Dutton and Company, 1923.
85. Sherman, H. C.: Chemistry of Food and Nutrition, ed. 3, New York, The Macmillan Company, 1926.
86. Shufeldt, R. W.: Formidable Powers of Electrical Fishes, Discovery **1:** 3, 1907.
87. —, and Dunn, L. C.: Principles of Genetics, New York, McGraw-Hill Book Company, 1932.
88. Tanner, F. W.: Bacteriology, New York, John Wiley and Sons, 1928.
89. Thayer, G. H.: Concealing Coloration in the Animal Kingdom, New York, The Macmillan Company, 1909.

90. Thomson, J. A.: The Outlines of Science (4 vol.), New York, G. P. Putnam's Sons, 1922.
91. Thone, F.: Billions of Insects to Fight Man's Battles, Science (News Service), 1929.
92. Transeau, E. N., Sampson, H. C., and Tiffany, L. H.: Text Book of Botany, New York, Harper and Brothers, 1940.
93. Van Niel, C. B.: Biochemical Problems of the Chemo-Autotrophic Bacteria, Physiol. Rev. **23**: 338-354, 1943.
    —, Rubens, S., and others: Radioactive Carbon as an Indicator of Carbon Dioxide Utilization, Proc. Nat. Acad. Sc. **28**: 8-15, 1942.
94. Walter, H. E.: Genetics, ed. 3, New York, The Macmillan Company, 1930.
95. —: Biology of the Vertebrates, New York, The Macmillan Company, 1928.
96. White, E. Grace: Principles of Genetics, St. Louis, The C. V. Mosby Co., 1940.
97. —: The Origin of the Electric Organs of Astroscopus Guttatus, Carnegie Publication, No. 252, 1918.
98. —: A Classification and Phylogeny of the Elasmobranch Fishes, New York, The American Museum of Natural History, 1936.
99. Wild Flower Preservation Society, Leaflets, Washington, D. C.
100. Wilson, E. B.: The Cell in Development and Inheritance, ed. 3, New York, The Macmillan Company, 1928.
101. —: Lectures.
102. Woodruff, L. L.: Animal Biology, New York, The Macmillan Company, 1932.

GLOSSARY

Abductor (Latin, *ab ducere,* to lead away from), a muscle which pulls a part away from the median line. In molluscs, the muscle which opens the shell.

Aboral, pertaining to the region opposite the mouth.

Absorption, the passage of substances through the walls of cells.

Acetylcholine, a chemical substance formed at the endings of the parasympathetic nerve fibers in vertebrates.

Acid, a compound, sour to the taste, which contains hydrogen replaceable by positive radicals to form salts, and which dissociates in water to produce hydrogen ions.

Acidosis, a condition of the blood caused by an excess of acid.

Activator, any organic substance, initiating specific activities of metabolism.

Adaptation, a structure, habit, or function which fits an organism for its environment; the process of becoming fitted to the environment.

Adductor (Latin, *ad ducere,* to lead toward), a muscle which draws a part toward the median line. In vertebrates toward the midventral line; in molluscs, the muscle which closes the shell.

Adventitious (Latin, *ad,* to; *venio,* I come), applied to plants or parts of plants introduced late; roots which do not arise from the primary root or its subdivisions.

Aeration, respiration through root hairs in plants.

Aerobe, a plant requiring free oxygen for respiration, and so unable to exist without air.

Afferent (Latin, *ad fero,* to carry toward), applied to a neuron which conducts a stimulus to the central nervous system.

Agriculture, a science dealing with the cultivation of the ground and the raising of crops.

Akene, a hard, dry, indehiscent fruit, consisting of one free carpel and usually one-seeded; *example*—buttercup.

Alary, pertaining to wings: hence, lateral.

Albino, an organism having no pigment or a deficiency of pigment, especially in the skin, hair, and eyes.

Alcohol, a colorless, volatile, inflammable liquid.

Chem. C_2H_5OH: water in which one of the hydrogen atoms has been substituted by an alkyl.

Aldehyde, a volatile liquid formed by the slight oxidation of an alcohol.

Chem., **a carbonyl group united on one side to an alkyl, and on the other to hydrogen.**

Alimentary, pertaining to digestion or to the digestive tract.

Alkaloid, one of the basic organic compounds of animal or vegetable origin, having marked physiologic action; *example*—ptomaines, morphine, caffeine.

Allele, one of a pair of genes occupying identical loci on homologous chromosomes.

Alternation of generations, the occurrence of two types of individuals in a single species; the one reproducing by asexual means, the other by sexual means, and each succeeding the other.

Alveolar, foamlike.

Ambulacral (Latin, *ambulare,* to walk). Term applied to the radial areas on echinoderms along which run the nerves and water tubes, and a series of tube feet.

Amino acid, the final cleavage product obtained from the digestion of protein foods.

Amitosis, division of a cell without spindle formation.

Amoebocyte, cells with amoeboid motion which live in the coelomic fluid of echinoderms; also, any cell with amoeboid properties.

Amorphous, having no determinate shape.

Amphiaster, the asters at the two poles of a spindle in mitosis.

Amphoteric, a property of proteins which enables them to react with either acids or bases.

Ampulla, a bulb at the base of the tube feet of echinoderms. A bulbous enlargement at the base of each semicircular canal of vertebrates.

Amyloplast, a colorless plastid in the cells of green plants which generates starch granules.

Anabolism, the constructive phase of metabolism.

Anaerobe, a bacterial type using oxygen released by its own activity from inorganic compounds, and so capable of existing in the absence of air.

Analogy, agreement between things in some circumstances but not in others. Specifically, agreement in function.

Anastomosis, the joining together of parts once separated, as of blood vessels, nerves, veins of a leaf, or parts of any network.

Anemia, a condition of the blood caused by an insufficient number of red blood corpuscles.

Anion, a negative ion.

Anode, the positive terminal of an electric source.

Annual, a plant which perishes within the year, after producing flower and fruit.

Antenna, one of a pair of sensory, jointed, head appendages in arthropods.

Anther, the part of a stamen in which the pollen sacs are found. Corresponds to a reduced leaf blade.

Antheridium, an organ in which male gametes are produced.

Anthocyanin, a red pigment in the leaves of plants, an oxidation product of carotene.

Anthracite, a hard coal containing few gases.

Anthropology, a science dealing with the study of ancient man and his development.

Anti-enzyme, an enzyme inhibiting the action of other enzymes.

Antipodal nuclei, three nuclei at the base of the embryo sac of seed plants formed by the division of the primary nucleus.

Antirachitic, opposed to the formation of rickets in bones.

Antitoxin, a soluble chemical compound in the blood or a plant cell which has the power of neutralizing the effect of some specific toxin.

Aorta, the large main artery which carries blood away from the heart.

Apical, pertaining to the end farthest from the point of origin as the apical bud or cell.

Apophysis, a swelling at the base of the capsule in mosses; a protuberance at the apex of a female scale in pine; a process from a bone for muscle attachment.

Appendicular, pertaining to the appendages of the body.

Aquatic, adapted to life in the water; water breathing.

Archegonium, the female sexual organ in embryophytes in which the female gametes develop.

Archenteric, pertaining to the embryonic digestive tract of the gastrula.

Archenteron, the embryonic digestive tract.

Artery, a blood vessel which carries blood away from the heart.

Arthropodial membrane, any membrane in arthropods which attaches a portion of the exoskeleton to the body.

Artefact, a formation seen in the cellular structure of stained sections due to the fixation process.

Ascospore, a spore produced in an ascus.

Ascus, a spore sac normally producing eight ascospores.

In yeasts, a swollen cell functions as an ascus but produces only four ascospores.

Assimilation, the conversion of the end products of digestion and other materials into protoplasmic structures. (See also intussusception.)

Asymmetry, a condition in which the organs on one side of a bilateral organism are unlike or unequal to those on the other side.

Atom, the unit of formed matter composed of one or more electrons, surrounding a nucleus of one or more protons.

Attraction sphere, the clear space surrounding the centriole in a centrosome.

Auditory, pertaining to the function of the ear, or to hearing.

Autonomic, self-governing. Said of those nerves which supply the internal organs and are not under the control of the will; the involuntary nervous system.

Autosome, any chromosome not designated as a sex chromosome.

Autotomy, the voluntary removal of an organ, as the ray of a starfish, by the organism itself.

Autotrophic, able to synthesize all substances required for nutrition from inorganic food substances (*see* heterotrophic).

Auxin, a growth hormone in plants.

Axial gradient, the orderly arrangement of regions along an axis showing graded differences in metabolic rate from one extreme to the other.

Axis, a straight line, real or imaginary, between two points, as between two sides or ends of an organism.

Axone, the projection from a neuron which conducts a stimulus away from the cell body.

Bacteria, one-celled plants without chlorophyll and without organized nuclei.

Bacteriology, a science dealing with the structure and activities of the Bacteria.

Base, an inorganic compound containing the hydroxyl radical.

Bast, the tissue of a vascular plant known as the phloëm.

Behavior, the sum total of an organism's reactions to its environment.

Behaviorism, a term used by a behaviorist to cover a reaction or set of reactions not involving consciousness. The term applies equally to animals and to man.

Behaviorist, one who treats the behavior of man and of animals on the same plane.

Beriberi, a disease involving inflammation of the nerves and muscular debility, caused by the lack of vitamin B in the diet.

Berry, a fruit in which the entire pericarp is fleshy, enclosing one or more seeds; *example*—grape.

Biennial, a plant which lasts two years, producing only leaves in the first year, and fruit and seed in the second.

Bilateral symmetry, a plan of organization in animals whereby the organs on the two sides of the midline are mirrored images of each other.

Binomial nomenclature, a system standardized by Linnaeus whereby each organism is given two Latinized names; a genus name, and a species name.

Biology, the science of life.

Biometry, the study of organic differences by statistical methods.

Biotic, pertaining to life, vital; applied to those factors in a community dependent upon the relationships of animals and plants.

Biramous, having two branches.

Bisexual, having two sexes in one individual; hermaphrodite.

Bituminous, pertaining to a soft coal containing large quantities of volatile matter.

Blastocoele, the hollow space inside a blastula.

Blastomere, one of the cells produced by the early divisions of an egg.

Blastopore, an embryonic mouth. The opening of the archenteron of the gastrula.

Blastostyle, the axis of the gonangium of a hydroid colony which produces medusae by budding.

Blastula, a stage in the development of the embryo, consisting of a hollow ball of cells in a single layer.

Blepharoplast, a kinetic granule at the base of a flagellum, derived from a centrosome.

Book lung, the respiratory organ of spiders, composed of flat sheets joined together like the pages of a book.

Botany, the science of plant life.

Brachydactyly, having short fingers or toes.

Branchial, pertaining to the gill region.

Brownian movement, magnified molecular motion, first described by Robert Brown.

Buccal, pertaining to the mouth cavity.

Buffer, a substance, such as a carbonate or phosphate, which will absorb excess acid from a solution.

Bulb, a short underground stem with fleshy leaves; *example*—lily.

Byssus, a thread, or a bunch of threads, used to attach certain molluscs to a substratum.

Caecum, a blind pouch opening off a digestive tract.

Calyptra, any caplike covering of a fruit or flower; crown of the capsule in mosses.

Calyx, a collective term for the sepals of a flower (often green); the outermost floral envelope.

Cambium, a layer of growing cells between the phloëm and the xylem cells of the vascular bundles, and contributing to both tissues continually.

Cannon bone, the elongated metacarpal or metatarsal of a horse's foot.

Capillary, one of many small vessels conveying blood from arteries to veins or from one vein to another.

Capsule, a dry dehiscent fruit composed of two or more carpels and having many seeds; *example*—poppy.
The theca of mosses.

Carbohydrate, a class of organic compounds containing carbon atoms in units of six combined with hydrogen and oxygen in the relation of two to one. A food substance required in the diets of all animals and plants.

Carboxylase, an enzyme which splits the carboxyl (COOH) group of amino acids yielding CO_2.

Cardiac, pertaining to the heart.

Carnivorous, living on a diet consisting solely of animal food; flesh-eating.

Carpellate, pertaining to the macrosporophyll of plants and its products.

Cartilage, a flexible, somewhat translucent material composed of cells embedded in a matrix.

Cartilage bone, bone formed by the ossification of cartilage; replacing bone.

Cast, a mold showing the shape of an organism in rock; a fossil.

Catalyst, a substance essential to, or hastening, a chemical reaction which does not itself take part in the reaction.

Cathode, the negative terminal of an electric source.

Cation, a positive ion.

Caudal, pertaining to the region of the tail.

Cell, a mass of protoplasm, usually containing a nucleus.

Cellulose, an insoluble carbohydrate, the chief constituent of cell walls in plants, and used in the manufacture of linen, paper, etc.

Centriole, the minute, darkly staining body in the center of the attraction sphere of a centrosome.

Centrosome, a body in the cytoplasm of certain cells which initiates spindle formation. It consists of a centriole in an attraction sphere.

Cephalic, pertaining to the region of the head.

Cephalization, the process of forming a head.

Cerebral, pertaining to the brain.

Cervical, pertaining to the neck.

Chemotrophic, able to obtain energy from inorganic substances.

Chemotropism, the reaction of an organism to chemical stimuli.

Chitin, the cuticle of the grasshopper, so called from its horny nature. A secretion from the epidermis.

Chloragogue cells, an outer layer of cells on the intestine of the earthworm.

Chlorenchyma, that tissue in a green plant which produces the chloroplasts.

Chlorophyll, the green substance in chloroplasts which absorbs light rays and so functions in photosynthesis.

Chloroplast, the type of plastid produced by the chlorenchyma which contains the chlorophyll and is a center of sugar formation.

Cholesterin, a lipoid substance found in animal tissues. In bile it is the substance which crystallizes to form gallstones.

Chondriocont, a chondriosome in the shape of a rod or a filament.

Chondriosome, a self-perpetuating granule in the structure of protoplasm which continually changes shape and position.

Choroid, pertaining to the vascular coat of the eye, between the sclerotic coat and the retina.

Chromatin, the deeply staining substance in the nucleus of a cell from which the chromosomes are formed prior to mitosis. This material is believed to be the seat of the hereditary factors.

Chromatophore, *Bot.* One of the plastids in plant cells which produces color.

Zool. A cell producing pigment; usually capable of changing size and form.

Chromidia, chromatin material scattered throughout the protoplasm of cells with no organized nucleus.

Chromomere, one of the minute knots of chromatin material having a linear arrangement on a chromosome.

Chromoplasts, one of the plastids in the cytoplasm of animal and plant cells which develops pigment and so gives color, other than green, to the tissues.

Chromosome, one of the masses of chromatin united during mitosis in a linear arrangement, and assuming characteristic form and position in any species.

Cilia, threadlike strands of protoplasm which, by acting in unison, create currents in liquids, and so cause movement.

Cirri, soft, fleshy projections or appendages.

Cleavage, the division of an egg.

Cleidoic, pertaining to egg membranes impermeable to water.

Cloaca, the common chamber into which the urinary, intestinal, and genital canals empty in species having a single anal aperture.

Clypeus, the section of the epicranium of the grasshopper directly below the forehead and to which the labrum is attached.

Cnidoblast, one of the formative cells of coelenterates which form the nematocysts.

Coccyx, the posterior portion of the spinal column in man.

Coelom, a true body cavity, lying between the body wall and the digestive tract, and lined with mesoderm cells.

Coelomate, possessing a coelom.

Coenocytic, an aggregation of protoplasmic units within a common wall; a multinuclear condition.

Coenogamete, a multinucleate mass of protoplasm, the individual nuclei of which have sexual functions.

Coenoscarc, the granular inner layer of the stalk and branches of a hydroid colony containing an inner cavity which is continuous with the cavity of the polyps.

Coenzyme, a chemical substance essential to the activity of an enzyme.

Cohesion, an attraction by which the particles of a body are united throughout a mass.

Cohesive force, the power exerted by the attraction between particles of a mass.

Cold blooded, a condition in which an organism's temperature fluctuates with that of the external environment.

Collenchyma, the supporting tissue just under the epidermis of the higher plants, having thickened and elongated cell walls.

Colloid, a mixture in which particles larger than molecules are suspended in a formless substratum. The suspended particles constitute the internal phase and the substratum the external phase.

Colony, a group of individuals of the same species united organically together.

Color blindness, inability to distinguish between colors, as between red and green.

Columella, *Bot.* A central axis, as in the capsule of mosses.

Zool. A bony rod in the middle ear of amphibians and reptiles, formed from the quadrate bone.

Commensal, an organism living with another and sharing its food, without harm to either.

Companion cells, a row of cells accompanying each sieve tube in the vascular bundle, and assisting in the function of the sieve tube.

Condensation, the concentration of molecules into a compound, as of dextrose into starch. The reverse of hydrolysis.

Conductility, the condition in protoplasm which makes possible the conduction of a stimulus.

Conduction, the passage of a nerve impulse or stimulus along a nerve or through protoplasm.

Condyle, an articular prominence on a bone.

Conjugation, the lateral union of two cells for the purpose of exchanging or fusing nuclear material. The lateral association of two chromosomes prior to reduction.

Conjunctiva, a mucous epithelium which covers the transparent cornea and is continuous with the lining of the eyelid.

Conjunctivitis, an inflammation of the conjunctiva.

Contractile vacuole, a vacuole which periodically expels its contents to the outside of the cell, and thus performs an excretory function.

Copulation, the sexual union of two organisms for the purpose of introducing the male gametes into the body of the female.

Coral, a coelenterate polyp or colony with calcareous or horny skeletal parts.

Cork cambium, the ring of dividing cells under the epidermis in vascular plants which gives rise to cork on the outside and to parenchyma on the inside.

Corm, a modified fleshy stem, usually underground, and having a few modified scale leaves; *example*—crocus.

Cornea, the transparent portion of the sclerotic coat which covers the exposed portion of the vertebrate eye.

Corolla, a collective term for the petals of a flower: the inner floral envelope.

Cortex, that area of the stem of vascular plants between the epidermis and the stele, containing, if present, the collenchyma and endodermis.

Cotyledon, the first leaves of the embryo contained in the seed before germination, and furnishing nourishment for the seedling.

Coxa, the globular segment on the leg of the grasshopper which attaches the leg to the body.

Cranial, pertaining to the cranium.

Cranial nerves, nerves which have their origin in the brain.

Cranium, that part of the vertebrate skull which encloses the brain.

Crenate, minutely notched.

Cretin, a dwarfed individual born without a thyroid gland.

Crossing-over, the rearrangement of linked characters due to the exchange of homologous genes during synapsis.

Crystalloid, a substance which in solution will pass through cell walls, such as sugars and salts.

Cuticle, a lifeless layer secreted by the epidermis of animals and plants.

Cutin, a waxy substance, which when combined with cellulose, makes the cuticle of plant cells impervious to water.

Cytology, a branch of biology dealing with the structure of cells.

Cytoplasm, the protoplasm surrounding the nucleus of a cell.

Cyst, a small capsule or sac.

Deaminase, an enzyme that splits the ammonia radicale from amino acids.

Deaminization, the removal of the ammonia radical from amino acids, as in the liver of vertebrates.

Decay, a type of bacterial fermentation occurring in the presence of air.

Deciduous, falling off at maturity or at certain seasons, as the leaves of a tree or the horns of a deer.

Dehiscence, the spontaneous opening of seeds, anthers, and dry fruits when ripe.

Dehydration, the removal of water from a substance.

Deliquescence, the process of absorbing moisture from the air.

Deliquescent branching, melting away, as when a stem loses itself by repeated branching.

Demarcation current, the passage of an electric current from an injured surface to an uninjured tissue due to the difference in potential caused by the injury.

Dendrite, one of the projections from a neuron which receives stimuli and conducts them to the cell body.

Denitrification, the reduction of nitrates by bacterial action, causing the release of free nitrogen into the air.

Depressor, a muscle which lowers a part.

Dermal bone, bone formed from the dermis of the skin and not preceded by cartilage.

Dermis, the inner layer of the skin, formed from mesoderm cells.

Dextrose, the final cleavage product obtained by the digestion of carbohydrate foods. Same as glucose.

Diabetes, a disease of the pancreas interfering with the normal oxidation of sugars.

Diaphragm, a muscular partition between the thoracic and abdominal cavities in mammals.

Diastase, an enzyme present in seeds and in saliva capable of converting starch into maltose and dextrin.

Dichotomous, dividing into two branches at each subdivision.

Dietetics, a medical study of the diet.

Differentiation, a difference between parts at two extremes of an axis. The act of attaining differences of structure or function in development.

Diffraction, the deflection of rays of light when passing through narrow slits to produce fringes of parallel light and dark or colored bands.

Diffusion, the tendency of molecules of gases and liquids to move from a position of greater density to one of less density until distribution is equal.

Digestion, a chemical process of hydrolysis activated by specific enzymes by which the complex food substances are reduced to simpler compounds.

Dihybrid, offspring of parents differing in two specific hereditary characters.

Dimorphic, existing in two sizes or forms.

Dioecious, in plants, having the staminate and pistillate flowers on separate plants.

In animals, having separate sexes.

Diploid, having two sets of chromosomes: typical of somatic tissues and of the tissues of the sporophyte in plants.

Dissociation, a reversible decompensation in a substance, as when a salt in solution is decomposed into ions and will again crystallize out as a salt.

Distal, remote from the point of origin; opposed to proximal.

Dizygotic, derived from two zygotes (fertilized eggs). Said of fraternal twins.

Dominant, said of inherited characters which are expressed even in the presence of a recessive gene.

Dorsal, the morphologic back of an animal; opposed to ventral.

Drone, the male bee.

Drupe, a form of fruit in which the exocarp is fleshy, the endocarp forming a stone; *example*—peach.

Duodenum, the first of the three divisions of the small intestine, next to the stomach. It receives secretions from the pancreas and from the liver.

Dyad, the double chromosome formed by the division of a tetrad into two parts.

Ecdysis, the process by which a grasshopper sheds its chitinous exoskeleton during growth.

Ecology, a branch of biology dealing with animal and plant life in relation to its environment.

Ectoderm, the outermost of the three primary germ layers.

Ectoplasm, the outer mass of protoplasm in one-celled organisms. It is less fluid than the endoplasm.

Efferent (Latin, *ex fero*, to carry away from), applied to a neuron which conducts a stimulus away from the central nervous system.

Egestion, the voiding of undigested matter from the rectum in animals.

Egg, a female germ cell after maturation. The female gamete.

Elater, any elastic springing organ, as the filament used for the dispersal of spores.

Electrolyte, a substance which in solution decomposes into ions and will conduct electricity; i.e., acids, bases, and salts.

Electrolytic dissociation, decomposition of an electrolyte into electrically charged ions which will conduct an electric current.

Electromagnetic waves, electrical lines of force radiating from electrons in space and producing a magnetic force. Origin believed to be in the sun.

Electron, a unit of negative electricity having a mass about one-thousandth of that of the hydrogen atom. An electron added to an atom causes a negative electrical charge; an electron removed from an atom causes a positive charge.

Element, a substance not separable into substances different from itself.

Embryo, the early stages of development in an organism.

Embryology, a branch of biology dealing with the early stages of development in animals and plants.

Emulsoid, a colloidal system in which the internal phase is very finely divided and which has not the power of gelation.

Endarch, applied to a stele where the protoxylem is wholly centrifugal.

Endocarp, the inner wall of the pericarp in the ovary of seed plants.

Endocrine gland, a gland whose secretions pass directly into the blood stream thus affecting organs at some distance from the gland; a ductless gland.

Endoderm, the innermost of the three primary germ layers.

Endoenzyme, an enzyme secreted in every cell and active in the processes of metabolism.

Endomixis, a process occurring within a cell accomplishing the same purpose as conjugation with another cell.

Endoplasm, the inner mass of protoplasm in a one-celled organism.

Endoskeleton, an internal supporting structure, as the bony framework of vertebrates.

Endosperm, the albumin of a seed in angiosperms; the prothallium within the embryo sac of gymnosperms.

Endothermic, storing energy in potential form, said of constructive phases of metabolism.

Endotoxin, applied to a toxin which is retained within the cell secreting it.

Energy, the capacity to do work.

Enterocoele, the cavity of the digestive tract.

Entomology, a science dealing with insect life.

Enzyme, a chemical substance secreted in a cell or in a gland and having specific catalytic action.

Ephyra, the young medusa of the Scyphozoa produced by the strobila.

Epicranium, the cuticle of the six anterior segments of the grasshopper fused into a boxlike exoskeleton.

Epidemiology, a medical science dealing with questions related to the spread of disease and the control of epidemics.

Epidermis, *Bot.* The single layer of cells forming the outer integument of vascular plants.

Zool. The outer epithelial layer of an animal's skin.

Epiphyte, a plant which grows on other plants, gaining support but not nourishment; not parasitic.

Epistatic, said of a factor which masks or prevents the expression of another factor in heredity, but is not the allelomorph of it. The hidden factor is hypostatic.

Epithelium, a layer of cells covering a surface or lining a cavity.

Equatorial plate, the group of chromosomes arranged on the equator of the spindle during mitosis.

Erosion, the wearing away of rock through the action of wind, water, and other agencies.

Ether, *Chem.* a volatile, inflammable liquid with anesthetic properties, consisting of water molecules in which both the hydrogen atoms have been substituted by alkyls.

Physics. Name formerly applied to all space, even that occupied by solids and liquids. It transmits light waves, electromagnetic waves, etc.

Ethmoid, pertaining to the region of the walls and septum of the nasal cavity.

Eugenics, the application of known laws of heredity to the human race.

Eustachian tube, the persistent first gill slit leading from the pharynx to the middle ear in the higher vertebrates.

Euthenics, the science dealing with the improvement of the human race through the improvement of the environment.

Exarch, applied to a stele in which the protoxylem is wholly centripetal.

Excurrent branching, having a central stem with branches regularly disposed about it, as a hemlock.

Exocarp, the outer wall of the pericarp in the ovary of a seed plant.

Exoskeleton, any supporting or protecting structure secreted by the outer part of an organism, as the chitin in insects, or the shell in molluscs.

Exothermic, releasing energy, said of destructive phases of metabolism.

Extensor, a muscle which extends a part.

F_1, the first filial generation following a cross between individuals possessing unlike hereditary traits.

F_2, the second filial generation obtained by a cross between two members of an F_1 generation.

F_3, the third filial generation obtained by a cross between two members of an F_2 generation.

Factor (see gene).

Facultative, the ability to change methods of living to suit conditions.

Fat, an organic compound composed of glycerin and fatty acids, and yielding these on hydrolysis. A food substance required in the diet.

Fermentation, a chemical action due to enzymes in which by-products are formed, as when alcohol is formed from sugar.

Fertile, capable of reproducing or bearing fruit.

Fertilization, the union of the female and male gamete preceding development.

Fertilizin, a substance secreted by the cortex of an egg which has the power of activating the sperm of the same species.

Fibrin, a white, fibrous protein material formed during the coagulation of blood and making the basis of a clot.

Fission, reproduction by division.

Flame cell, a cell containing a group of vibratile cilia which function as a part of the excretory system of flatworms.

Flexor, a muscle which bends one part on another.

Fluctuations, somatic variations resulting from differences in environment rather than heredity.

Foliage, a collective term for the leaves of a plant.

Follicle, a dehiscent dry fruit consisting of one carpel. The seeds are attached to a ventral suture; *example*—milkweed.

Fragmentation, a process by which a cell divides into several parts at one time, usually preceded by nuclear division.

Freemartin, the partially masculinized female born twin to a male in cattle.

Frons, the forehead, or front dorsal region of the epicranium of the grasshopper and allied insects.

Funiculus, the stalk which attaches the ovule to a placenta in the ovary of an angiosperm.

Galvanotropism, reaction of an organism to an electric current.

Gamete, a mature germ cell before fertilization; either male or female. It contains the haploid number of chromosomes.

Gametophore, the portion of a filament which produces gametes.

Gametophyte, the generation of a plant which has the haploid number of chromosomes, and produces the gametes.

Ganglion, a group of nerve cells usually appearing as a thickening of a nerve.

Gastral, pertaining to the stomach.

Gastrocoele, a stomach cavity. The intestinal canal in coelenterates.

Gastrula, a stage in the development of the embryo consisting of two layers of cells surrounding a cavity which communicates with the exterior.

Gel, the state of a colloidal system in which the external phase is more solid than the internal phase.

Gelation, the act of forming a gel; a property of protoplasm.

Gemma, an asexual growth on liverworts, analogous to a leaf bud.

Gemmation, the process of reproduction by budding.

Gemmule, a reproductive body composed of a number of cells.

Gena, one of the cheeks, or lateral portions of the epicranium of the grasshopper and allied insects.

Gene, a chemical activator situated in the chromatin material which stimulates development in specific directions. A unit of heredity.

Generative nucleus, one of the two nuclei at the forward end of the pollen tube.

Genetics, the science which deals with variation, heredity, and sex phenomena in animals and plants.

Genital, pertaining to reproduction, or to the reproductive organs.

Geotropism, the reaction of an organism to the forces of gravity.

Germ cell, a cell specialized for sexual reproduction.

Germinal continuity, the theory that germ plasm is continuous from one generation to the next.

Germination, the initiation of growth in a seed.

Germ layer, one of the primary layers of cells formed early in the development of an embryo, and from which the tissues and organs of the animal develop.

Germ plasm, a collective term used for the protoplasm of any organism specifically set apart for handing down hereditary traits from one generation to the next; opposed to somatoplasm.

Gibb's principle, anything which when dissolved lowers the surface tension of the solvent will tend to collect at the free surface.

Gland, an organ which has the power of secreting something to be used by the body.

Glochidium, a bivalve larva of molluscs which lives temporarily as a parasite on the body of a fish.

Glomerulus, a coil of capillaries found at the end of each of the nephric tubules in the kidneys of higher vertebrates.

Glucose, the commercial form of dextrose; grape sugar. (See dextrose.)

Glycogen, a form of animal starch formed by animal tissues for storage purposes, as in the liver of vertebrates.

Goiter, an enlargement of the thyroid gland with or without nervous disturbances.

Golgi apparatus, a reticular network in the cytoplasm of a cell composed of plastic bodies, and usually placed with relation to the polarity of the cell.

Gonad, an organ in which germ cells of either sex are produced.

Gonangium, the reproductive individual of a hydroid colony.

Gonotheca, the transparent horny case surrounding each gonangium of a hydroid colony and continuous with the perisarc.

Grain, an indehiscent dry fruit of the cereal grasses.

Graphite, soft black carbon with a metallic luster. Its presence in rocks indicates the previous existence of organic life.

Ground meristem, one of the three primary meristems of the vascular plants destined to form the tissues of the cortex pericycle and pith.

Growth metabolism, the phase of anabolism involving the synthesis of protoplasm out of the amino acids of protein digestion.

Gustatory, pertaining to the sense of taste.

Guttation, the exudation of drops of liquid from plants due to excessive pressure from within.

Gynandromorph, an organism with female organs on one side and male on the other.

Habitat, the environment in which an organism or species lives.

Haploid, the reduced chromosome number, found typically in the cells of the gametophyte and in gametes.

Haustorium, a growth from a parasitic plant which penetrates the tissues of the host and absorbs nourishment.

Heliotropism, the reaction of organisms to sunlight.

Hemocoele, a body cavity, or coelom, which is morphologically an enlarged blood space.

Hemoglobin, the red coloring matter of the blood, which is capable of carrying oxygen.

Hemolysis, the condition of blood in hypotonic solutions. The corpuscles burst and the hemoglobin is in solution.

Hemophilia, a tendency to profuse bleeding from even slight wounds due to failure of blood to clot in normal time.

Hepatic, pertaining to the liver.

Herb, a plant with no persistent stem above the ground.

Herbal, a book containing the names and descriptions of herbs, or of plants in general, with their propertis and virtues.

Herbivorous, living on a dict of plants.

Hermaphrodite, an organism possessing both male and female reproductive organs.

Herpetology, a science dealing with the study of reptiles.

Heterocyst, a large inert cell in filamentous algae, which separates contiguous hormogonia.

Heterotrophic, requiring organic compounds for food, to be taken in from the outside.

Heterozygote, an organism in which the two allelomorphic factors for one or more inherited characters are composed of different elements.

Heterozygous, a condition in a zygote where the allelomorphic pairs of factors are composed of unlike elements and therefore produce two kinds of gametes.

Hibernate, to go into a dormant state for the winter.

Histology, a branch of biology dealing with the study of tissues.

Holophytic, a type of nutrition found in green plants where food substances are synthesized from inorganic compounds by the aid of chlorophyll and sunlight.

Holozoic, a type of nutrition found in the majority of animals, involving the ingestion of raw materials captured by the organism.

Homogeneous, composed of similar parts or elements.

Homologous, having a like or similar structure.

Homology, correspondence between things. The similarity of structure between organs of different species, a mark of organic relationship.

Homozygous, a condition in a zygote where the allelomorphic pairs of factors are composed of similar elements, and, therefore, produce but one kind of gamete.

Hormogonia, sections of filaments in the algae which separate off and form new filaments.

Hormone, a chemical substance secreted by a gland and having a specific action on some organ or organs at a distance from the gland. The substance is continually used up during the reactions.

Host, an organism which harbors a parasite.

Hyaline, transparent, formless. Applied to the clear substratum of protoplasm.

Hyaloplasm, the formless external phase of protoplasm.

Hybridization, the crossing of animals or plants having unlike hereditary characters.

Hydration, the absorption of water by cells with subsequent swelling.

Hydrogen, a gas having the simplest known atomic structure consisting of one proton and one electron. The positive radical of an inorganic acid.

Hydrogen ion, the positive ion (H+) which gives to any acid its acid properties.

Hydrogen ion concentration (pH), the index of acidity, based on the number of hydrogen ions in any solution.

Hydroid, one of the colonial coelenterates, each individual of which resembles a Hydra.

Hydrolysis, a chemical process by which molecules of water are added to a compound, as in the digestion of starch to dextrose.

Hydrophyte, a plant adapted to life in the water.

Hydrotheca, a horny, transparent cup surrounding each polyp of a hydroid colony and continuous with the perisarc.

Hydrotropism, the reaction of an organism to water.

Hydroxyl, the negative radical OH in inorganic compounds.

Hydroxyl ion, the negative ion (OH–) which gives to any base its alkaline properties.

Hygroscopic, readily absorbing and retaining moisture.

Hypertonic, having an osmotic pressure greater than that of protoplasm.

Hypha, a filament of a fungus.

Hypocotyl, the stem of the embryonic plant in a seed.

Hypoglossal, pertaining to the region under the tongue.

Hypotonic, having an osmotic pressure less than that of protoplasm.

Ileum, the last and longest division of the small intestine.

Immunity, protection acquired or natural against a specific disease.

Immunology, a science dealing with questions of acquired immunity in the treatment of disease.

Inclusion, a formed body in the structure of a cell made by the protoplasm.

Indusium, *Bot.* An outgrowth from a leaf covering the sorus.
Zool. The covering of a larval insect.

Inflorescence, method of flowering; general arrangement of flowers on an axis.

Insulin, the substance extracted from the pancreas and capable of causing oxidation of sugars.

Integument, a covering. The covering of an organ or body, as the skin. The envelope of an ovule.

Intercellular, lying or passing between cells.

Intersex, an individual having some male and some female characters so intimately mixed as to give the appearance of an intermediate.

Interzonal fibers, the threads in the center of the spindle in cell division which are retained until the process of division is complete.

Intestine, that section of the digestive tract leading from the stomach to the anus.

Intracellular, passing through cells.

Intussusception, the synthesis of new tissue from the products of digestion.

Invagination, the folding of a layer of cells inward into a cavity, as in the gastrula.

Investing bone (see dermal bone).

Ion, one of the two parts into which a molecule may separate when dissolved in water.

Irritability, the condition in protoplasm which makes possible the receipt of a stimulus.

Isotonic, having an osmotic pressure equal to that of protoplasm.

Isotope of an element, having the same atomic number but a different atomic weight, as Carbon 12, and Carbon 13.

— **of a molecule**, having the same chemical formula, but a different arrangement of atoms, as dextrose and levulose.

Jejunum, the middle section of the small intestine.

Jugular vein, the large vein returning blood from the head to the heart.

Karyokinesis, a process of cell division initiated in the nucleus. (See mitosis.)

Katabolism, the destructive phase of metabolism.

Keratin, a horny substance found in horn, hair, nails, etc.

Kinetic, activity involving motion; opposed to static.

Kinetic energy, the energy exerted by a body at work.

Labial, pertaining to the lips.

Labium, the lower lip of many insects.

Labrum, the upper lip of many insects.

Lacrimal, pertaining to the organs producing tears, or to the region adjoining.

Lacuna, an intercellular space, or a space between tissues.

Lamella, a thin layer.

Larva, a free-living stage in the development of an animal which must pass through a metamorphosis to attain adult form.

Larynx, the enlargement at the anterior end of the trachea containing the vocal cords.

Lenticel, an area of loose tissue in plant stems through which air enters the plant.

Leucocyte, a white blood corpuscle.

Levator, a muscle which raises a part.

Lichen, a composite organism composed of a fungus living symbiotically with an Alga.

Life cycle, the series of events occurring in an organism from one generation to the next, beginning and ending with the formation of a sexual cell.

Life history, the series of events occurring in an individual from origin to death.

Ligament, a tough band of fibrous connective tissue which attaches a muscle to a bone or to another muscle.

Lignin, a substance which in combination with cellulose forms the woody tissue of plants.

Limestone, a rock formed mainly from organic remains, such as shells and corals, and consisting of calcium carbonate.

Linin, an achromatic substance in the nucleoplasm of a cell which forms the network on which the chromatin granules are held.

Linkage, a type of inheritance in which genes on the same chromosome tend to remain together in transmission more often than they separate.

Lipochrome, coloring matter containing a lipoid substance.

Lipoid, a substance having chemical and physical properties resembling those of fats, but not itself a fat.

Luciferase, an enzyme activating the oxidation of luciferine, thus causing it to glow.

Luciferine, a luminous substance secreted by gland cells which will only glow when oxidized.

Lumbar, pertaining to that part of the spine which is back of the ribs.

Macronucleus, the larger nucleus in protozoan cells where dimorphic nuclei exist. Supposed to have a vegetative function.

Macrosome, the larger of the granules suspended in the hyaloplasm of protoplasm.

Macrospore, the larger spore of a heterosporous plant. Applied also to the ovule.

Macrosporophyll, a modified leaf supporting the macrospore. A carpel.

Malpighian body, a structure in the vertebrate kidney composed of a Bowman's capsule and a glomerulus.

Malpighian tubules, the tubules surrounding the intestine of insects which have the function of excretion.

Maltase, an enzyme found in plants, in saliva and in the pancreatic secretion which completes the digestion of starch, changing maltose to dextrose. (See diastase.)

Mandible, a jaw. The lower jaw of mammals. The second pair of jointed head appendages in arthropods.

Mantle fibers, the threads of the spindle in cell division which extend from the poles to the circumference of the equator and which precede the chromosomes to the poles.

Manubrium, a projection from the subumbrella of a medusa which bears the mouth at the free end.

Maturation, the process through which germ cells pass in becoming mature gametes, and during which the chromosome number is reduced.

Maxilla, one of the third or fourth pairs of head appendages in arthropods.

Medusa, a free-swimming coelenterate; a jellyfish.

Meiosis, the process of maturation.

Meiotic phase, the place in a life history at which the maturation process occurs.

Meristem, the growing tissue of a plant.

Mesarch, applied to a stele in which the protoxylem is entirely surrounded by the primary wood.

Mesentery, a double membranous wall connecting an intestine with the body wall. In vertebrates the mesenteries surround the intestines also.

Mesoderm, the germ layer lying between the ectoderm and endoderm. The last germ layer to form.

Mesogloea, a jellylike substance found between the two cell layers of coelenterates, and secreted by both layers. Not made of cells and, therefore, not a germ layer.

Mesonephros, the second embryonic kidney of vertebrates, replacing the pronephros. Functional in the adult amphibia and in most fishes. The wolffian body.

Mesophyte, a plant adapted to normal conditions, neither extremely wet nor dry.

Metabolism, the sum total of the chemical processes of protoplasm, anabolic and katabolic.

Metamerism, a plan of organization in animals whereby structures are serially repeated and the body is divided into segments or regions.

Metamorphosis, a type of development in animals involving a change in form between the larval stage and the adult.

Metanephros, the third embryonic kidney of vertebrates, growing out of the mesonephric duct, and replacing the mesonephros in all vertebrates above the Amphibia.

Metaphyta, plants consisting of more than one cell.

Metazoa, animals of more than one cell.

Microdissection, a method by which cells may be dissected or injected with solutions.

Micronucleus, the smaller of the two nuclei in protozoan cells where dimorphic nuclei exist. The kinetic nucleus, functioning in reproduction.

Micropyle, the opening in the skin of a seed marking the position of the radicle. The aperture of the ovule through which the pollen tube enters.

Microsome, the smaller of the granules suspended in the hyaloplasm of protoplasm.

Microspore, the smaller spore of a heterosporous plant; applied also to the pollen grain.

Microsporophyll, a modified leaf bearing the microsporangium; a stamen.

Mitochondria, chondriosomes in the form of granules, especially prominent during cell division.

Mitosis, cell division involving the formation of an achromatic figure, the spindle, and chromosomes; literally, a thread formation.

Mixotrophic, a combination in one organism of two types of nutrition.

Mold, minute saprophytic fungi which produce a mycelial growth on organic matter.

Molecule, the unit of a chemical compound composed of two or more atoms.

Monoecious, *Bot.* Having separate staminate and pistillate flowers on the same plant.

Zool. Producing both eggs and sperm in one individual; an hermaphrodite.

Monohybrid, the offspring of parents differing in but one pair of heritable characters.

Monozygotic, derived from one fertilized egg cell. Said of identical twins.

Morphology, the study of form. A branch of biology dealing with the structure of living things.

Motility, the power of spontaneous motion.

Mullerian duct, the oviduct of female vertebrates.

Mutation, a sudden variation in a species, originating in the germ plasm, and subsequently inherited.

Mycelium, the vegetative portion of the thallus in fungi; composed of hyphae.

Mylohyoid, the muscle between the two divisions of the tongue which elevates the floor of the mouth during the process of swallowing.

Myofibril, a contractile filament grown as a process from a cell.

Nares, internal or external openings of the nasal passages.

Nasal, pertaining to the nostrils.

Nematocyst, one of the stinging bodies of the coelenterates.

Nephritis, a disease of the kidneys commonly known as ''Bright's Disease.''

Nephrostome, the funnellike opening at the inner end of a nephridium.

Neuron, a nerve cell, consisting of a cell body with an axone and dendrites.

Nictitating membrane, a third eyelid found in frogs and some fishes.

Night blindness, an inability to see by twilight due to a defect in the brain.

Nitrification, the oxidation of nitrogen compounds derived from animals and plants to form nitrates through the action of three specific types of Bacteria.

Nonelectrolyte, a substance which is not ionized in solution and will not conduct an electric current; i. e., sugars and alcohols.

Nucellus, the body of the ovule or macrosporangium containing the embryo sac or macrospore.

Nucleolus, a spherical body suspended in the nucleoplasm and probably having a vegetative function.

Nucleoplasm, the protoplasm inside the nucleus of a cell.

Nucleus, the largest of the formed bodies of a cell containing nucleo plasm, and having chromatin granules caught in the nodes of a linin network.

Nutrition, the processes by which an animal or plant takes in and utilizes food substances.

Occipital, pertaining to the base of the skull.

Ocellus, one of the minute single eyes in insects.

Olfactory, pertaining to odor.

Ommatidium, one of the hexagonal lenses of the compound eye in insects.

Omnivorous, living on a diet of both animal and plant food.

Oöcyte, the egg during the process of maturation from the beginning of the growth period to the end of the second division.

Oögenesis, the maturation of the female germ cells.

Oögonia, the female germ cells prior to the process of maturation.

Oötid, the egg after the last maturation division is complete.

Operculum, a lid.

Bot. Covering of a capsule.

Zool. Covering of the gills in fishes. Horny plate on a gastropod foot.

Optic, pertaining to the eye.

Oral, pertaining to the mouth or mouth region.

Organ, in animals an organ is a group of tissues united for the performance of a special function.

Organelle, a term used to designate the structures in protozoan cells which perform the functions of organs in higher animals.

Organization, the structural plan on which an organism is built.

Ornithology, a science devoted to the study of bird life.

Osmosis, the movement of water from one side of a membrane to the other caused by a difference in molecular concentration on the two sides of the membrane.

Osmotic pressure, the force exerted by the pressure of molecules in solution against a membrane.

Ossicle, a small bone, or bonelike structure.

Ossification, the process of turning into bone.

Ostium, an opening in the wall of the heart in arthropods. An opening through which water enters a sponge.

Otic, pertaining to the ear.

Ovary, *Bot.* That part of the pistil which contains the ovules and ultimately becomes the fruit.

Zool. The female gonad containing the female germ cells which ultimately become mature eggs.

Oviparous, egg-laying.

Ovulation, the process by which fully matured eggs are released from an ovary.

Ovule, the potential seed in the ovary of a plant within which is the female gamete.

Oxidase, an enzyme which activates the oxidation processes of the body.

Oxidation, any one of several katabolic activities that release energy in the body of animals and plants; commonly the union of oxygen with dextrose.

Oxyhemoglobin, hemoglobin holding oxygen in a loose chemical combination.

Paedogenesis, sexual maturity in a larval organism.

Paleontology, a science dealing with the study of prehistoric animals and plants.

Pallial, pertaining to a mantle, as in molluscs.

Paramylum body, an inclusion in which starch is deposited in some one-celled organisms.

Parasite, a plant or animal living on, in, or with another living organism, the host, and at its expense.

Parasitology, a science dealing with the study of parasites and the treatment of parasitic disease.

Parasympathetic, that portion of the autonomic nervous system in vertebrates which secretes acetylcholine; opposed to sympathetic.

Parenchyma, fundamental tissues of green plants used chiefly for the storage of food.

Parietal, pertaining to the sides or walls of an object or cavity.

Parthenogenesis, development of an egg without fertilization.

Parthenogonidia, the asexual cells of a Volvox colony.

Peat, carbonaceous soil formed by partial decomposition of plants in water. The first step in coal formation.

Pectoral, pertaining to the breast. Applied to the girdle supporting the fore limbs of vertebrates.

Pediatrics, a science which deals with the treatment of children's diseases.

Pedicel, the term applied to the stem of each separate flower when more than one flower is attached to the main stem.

Peduncle, the stem or branch which bears a flower.

Pellagra, a skin disease with nervous symptoms caused by the lack of vitamin G in the diet.

Pellicle, the thin protoplasmic envelope surrounding the ectoplasm of certain Protozoa.

Pelvis, the bony structure supporting the hind limbs of vertebrates.

Penis, a copulatory organ.

Pepsin, an enzyme found in gastric juice and secreted by Protozoan cells which causes the digestion of protein foods to peptones, an intermediate product. It acts in an acid medium.

Perennial, a plant which does not perish after producing flower and fruit but lasts several years.

Perianth, a collective term for the floral envelopes of a flower, the calyx and corolla.

Pericardium, the lining of that division of the coelom which surrounds the heart.

Pericarp, the wall of the ovary in seed plants; the wall of the capsule in mosses.

Peripheral, pertaining to the surface of a body or to the circumference of a circle.

Perisarc, a transparent outer sheath of horny material surrounding the stalk and branches of a hydroid colony.

Peristome, the region surrounding the mouth.

Peritoneum, the membrane lining the abdominal cavity. It is continuous with the mesenteries.

Petal, one segment of the corolla of a flower.

Petiole, the stalk of a leaf.

Petrifaction, the substitution of mineral matter for organic matter in the remains of animals and plants.

Phagocytosis, the process by which leucocytes destroy microorganisms by ingestion.

Phloëm, the food conducting tissues of the vascular bundles; the bast.

Phototropism, the reaction of an organism to the stimulus of light, natural or artificial.

Phylogenetic, pertaining to the ancestral history of a race or species.

Physiology, the study of function. A branch of biology dealing with the functions of animals and plants.

Phytohormone, any one of the auxins, promoting growth in a plant.

Pigment, any coloring matter found in the tissues of animals and plants.

Pinna, *Bot.* The primary divisions of a leaf branching from the main axis.

Zool. (a) A feather.
(b) A species of bivalved Mollusc.

Pinnule, the secondary divisions of a leaf branching from the pinna.

Pistil, a collective term for the inner whorl of macrosporophylls inside the perianth of a flower. Composed of stigma, style, and ovary.

Pistillate, pertaining to the macrosporophyll and its products (see carpellate).

Placenta, *Bot.* The organ which bears the ovules in an ovary.

Zool. The organ which nourishes the embryo in many viviparous animals.

Plagiotropic, growth of a plant at an angle to the source of stimulus.

Plankton, floating oceanic life composed of animals and plants with weak locomotory power.

Plasma membrane, a delicate membrane of living protoplasm surrounding a cell, nucleus, or vacuole, and having special absorptive properties. Not a cell wall.

Plasmolysis, the shrinking of protoplasm away from a cell wall.

Plasmosome, an achromatic formed body in a nucleus (a nucleolus).

Plastid, any one of the living inclusions in a cell which are centers of chemical activity.

Pleuron, one of the lateral divisions of the cuticle on each segment of a grasshopper.

Plumule, the primary bud of the embryonic plant inside a seed.

Pod, a dry, dehiscent fruit with many seeds.

Polar body, a nonfunctional cell extruded from the egg at each maturation division.

Polarity, the condition of differentiation in protoplasm whereby two distinct regions or poles are established.

Polar nuclei, a fourth nucleus in each group at the two extremities of the embryo sac of seed plants which moves toward the center and there fuses to form the secondary nucleus.

Pollen, the dustlike powder produced by the anthers of flowers and composed of pollen grains.

Pollen sac, the microsporangium in seed plants inside which the pollen grains are formed.

Pollen tube, the tube which grows out of the pollen grain and passes from the stigma to the ovule.

Pollination, the placing of the pollen on the stigma or stigmatic surface of a flower; the transfer of pollen from one plant to another.

Polydactyly, having extra fingers or toes.

Polymorphism, the occurrence of several kinds of individuals in a colony, all members of which are derived from the same parent or parents.

Polyp, one of the feeding individuals of a hydroid or coral colony.

Polystele, a stem in which the stele is broken into separate bundles.

Pome, a form of fruit in which the exocarp forms the skin, the endocarp the core, and the fleshy material is formed by the receptacle which grows up and fuses with a portion of the exocarp to form a mesocarp.

Portal system, that part of a circulatory system in which veins break up into capillaries inside an organ without relation to arterial capillaries.

Potential energy, the energy contained in a body when not at work.

Potentiality, latent power not yet in action.

Proboscis, an anterior, protrusible portion of an alimentary canal.

Procambium, one of the three primary meristems of vascular plants destined to form the primary tissues of the vascular bundles.

Proenzyme, a chemical substance secreted in a cell or gland, the function of which is to activate another enzyme.

Promeristem, the rapidly growing cells at the tips of roots and stems which give rise to all the permanent tissues.

Pronephros, the first embryonic kidney of vertebrates, consisting of a duct and three tubules. Functional in the adult of cyclostomes and some fishes.

Pronotum, the enlarged tergite on the prothorax of the grasshopper.

Protein, an organic compound built up of amino acids, and containing nitrogen. A food substance required for growth of animal and plant tissues.

Protoderm, one of the three primary meristems of the vascular plants destined to form the epidermis.

Proton, the nucleus of the hydrogen atom. The unit of positive electricity.

Protonema, the platelike growth in mosses on which the conspicuous plant develops as a lateral or terminal shoot. Produced by a spore.

Protophyta, plants of one cell.

Protoplasm, the living substance of which organisms are made. A colloidal suspension of chemical compounds, such as carbohydrates, fats, and proteins, with vitamins and inorganic salts.

Protoplast, the living plant cell inside the cell wall.

Protostele, a primitive form of stele in which the phloëm surrounds a central shaft of xylem.

Protoxylem, the first elements of wood to form in a vascular bundle.

Protozoa, animals of one cell.

Protozoology, a science dealing with the one-celled animals.

Proximal, nearest to the point of origin or attachment.

Psychiatry, the study and treatment of mental disorders.

Ptomaine, an alkaloid formed by the action of bacterial putrefaction on proteins: often poisonous.

Pulmonary, pertaining to the lungs.

Pulvillus, one of the ventral pads on the tarsus of the leg in grasshoppers.

Pyrenoid, an inclusion for protein deposit in some cells.

Rachis, *Bot.* an elongated axis of an inflorescence.

Zool. that part of the shaft of a feather which bears the web.

Rachitic, of or pertaining to rickets.

Radial symmetry, a plan of organization in animals whereby a line drawn from any point on the circumference of the organism will divide the organism into two equal parts if passed through the center.

Radical, a molecular combination acting as a unit in chemical reactions.

Radicle, the primary root of an embryonic plant inside a seed.

Radioisotope, an element that has been bombarded by neutrons or other atomic projectiles and become radioactive for a brief period, as Carbon 14.

Radium, the active element of uranium oxide having the power of shooting radiations into the air at a terrific speed, due to the disintegration of radium atoms.

Radula, a masticatory organ in certain molluscs.

Recapitulation theory, the theory that animals in their embryonic development repeat the history of the race.

Receptacle, the axile of a flower which supports the whorls of the perianth and sporophylls.

Recessive, said of inherited characters that are concealed in the presence of a dominant character.

Reduction, (1) the reverse of all oxidation processes in metabolism, commonly the release of oxygen from a compound.

(2) the reduction of chromosome number from diploid to haploid.

Reflex action, an involuntary and unconscious act performed as the result of a stimulus passing over a reflex arc.

Reflex arc, two or more neurons, one sensory and one motor, forming a direct pathway for stimuli from sense organ to motor organ without passing through the brain.

Refraction, deflection of a ray of light when passing obliquely from one medium to another in which the velocity varies.

Renal, pertaining to the kidney.

Reorganization, the process of revitalizing protoplasm.

Replacing bone, bone formed by the replacement of preexisting cartilage: cartilage bone.

Reproduction, the process of producing offspring.

Respiration, an exchange of gases in an animal or plant whereby oxygen is received and carbon dioxide released.

Retroperitoneal, said of organs situated between the peritoneum and the body wall, as the kidney of vertebrates.

Retting, the exposure of hemp or flax to bacterial action to break down the cementing material by which bast fibers are joined to other tissues.

Rhabdites, rodlike bodies in the epidermis of flatworms.

Rheotropism, reaction of organisms to currents in water.

Rhizoid, rootlike filaments which grow down into a substratum and form an anchor for a plant, as in a mold.

Rhizome, horizontal underground stem.

Rhizopod, one of that class of Protozoa which moves by pseudopodial formation.

Rickets, a disease of childhood caused by the failure of bones to calcify properly, and due to the lack of vitamin D in the diet.

Root cap, a cap of inactive cells forming a protective area around the promeristem tissue of a root.

Rotator, a muscle which rotates one part on another.

Rugose, ridged or furrowed.

Runner, an elongate lateral stem rooting at intervals: a stolon.

Sacral, pertaining to the pelvic region.

Salt, a chemical substance containing a positive and a negative radical other than hydrogen or hydroxyl. It can be formed by the union of an acid with a base.

Samara, a dry, indehiscent winged fruit.

Saprophytic, a type of nutrition whereby organic compounds derived from dead tissues are synthesized for food material. Typical of some bacteria.

Saprozoic, a type of nutrition whereby dissolved proteins are ingested, thus eliminating capture.

Schizocarp, a dry, indehiscent fruit which splits into one-seeded sections.

Sclerite, any one of the divisions of the cuticle in the grasshopper and allied insects.

Scurvy, a dietary disease due to the lack of vitamin C, contracted when fresh food is eliminated from the diet.

Scyphistoma, an asexual individual of the Scyphozoa, resembling a reduced hydroid polyp.

Sea anemone, the individual polyp form of the Actinozoa.

Secondary sexual characters, an external character which distinguishes one sex from the other but which is not connected with the function of reproduction.

Secretion, a nonliving substance manufactured by living cells.

Seed, a fertilized and matured ovule of a seed plant.

Seedling, a young plant produced from a seed.

Segregation, the separation of allelomorphic genes into different gametes.

Semipermeable membrane, a membrane permeable to a solvent but impermeable to particular solutes.

Sepal, one segment of the calyx of a flower.

Septum, any dividing wall. The wall between two somites in annelids.

Serum, the yellowish fluid left in blood after a clot has formed.

Serum therapy, the treatment of disease by the injection of blood serum into a patient from some other animal.

Sessile, attached, as opposed to free living. Specifically attached without a stalk.

Sex chromosome, the chromosome designated as "X" or "W" through the distribution of which the sex ratio is maintained.

Shrub, a woody perennial with no main trunk or stem: a bush.

Sieve tubes, elongated cells in the phloëm of the vascular bundles which are perforated at the thickened end. Used to conduct food.

Silicon, a nonmetallic substance forming the basis of quartz, sand, and glass, and found in the skeletons of many animals and plants.

Sinus, *Bot.* A depression between adjoining lobes.
Zool. A blood space or enlarged blood vessel.
A cavity in the substance of the bone of the skull which communicates with the nasal passage and contains air.

Siphon, a tubular organ for drawing in or ejecting fluids.

Siphonostele, a stem in which the vascular tissue forms a complete tube around a central pith.

Sol, the state of a colloidal system in which the external phase is more liquid than the internal phase.

Soma, the somatoplasm.

Somatic, referring to body tissues as opposed to germ cells.

Somatoplasm, the tissues of an organism composing the body as opposed to the germ cells.

Somite, one of the segments into which the body of a metameric animal is divided.

Sorus, a cluster of sporangia. The fruit dots on fertile fern fronds.

Spermatid, the male germ cell formed by the last maturation division. The spermatid becomes the spermatozoon by a change of form.

Spermatocyte, the male germ cell during the process of maturation from the beginning of the growth period to the end of the second division.

Spermatogenesis, the maturation of the male germ cells.

Spermatogonia, the male germ cells prior to the process of maturation.

Spermatozoon, the mature male gamete: also called sperm.

Sphincter, a ringlike muscle surrounding a passage, such as the intestine, and capable of closing the passage by contraction.

Spindle, the achromatic figure formed during cell division, having the shape of a double cone of protoplasmic threads.

Spiracle, an air hole.

In fishes, the opening of the first gill slit.

Spiral valve, an infolding of the intestinal wall of some fishes, arranged spirally around an axis and increasing the absorptive surface of the intestine.

Splenial, referring to the upper dorsal region, back of the neck.

Spongin, a fibrous, horny material forming the skeleton of bath sponges.

Sporangiophore, a spore bearing hypha of a fungus which grows erect.

Sporangium, a sac which produces spores.

Spore, an asexual reproductive cell provided with a protective covering.

Spore mother cell, the cell produced by the sporophyte in which reduction of chromosomes takes place.

Sporophyll, a leaf which bears spores.

Sporophyte, the generation in a plant which has the diploid number of chromosomes and which produces spores.

Sporozoite, individuals formed by the zygote in Sporozoan parasites which infect new hosts.

Stamens, the outer whorl of microsporophylls inside the perianth of the flower which bear the male gametes.

Staminate, pertaining to the microsporophyll and its products.

Static energy, activity without motion: opposed to kinetic. Said of bodies in equilibrium or at rest.

Static stimuli, stimuli arising within a cell at rest.

Stele, that area of the stem in vascular plants which contains the pericycle, vascular bundles, and pith.

Sterile, incapable of reproduction or of bearing fruit.

Sternite, the ventral division of the cuticle on each segment of the grasshopper or allied insects.

Sternum, the breast bone.

Stipule, paired organs at the base of the leaf in some plants.

Stolon, see runner.

Striated, marked with a series of narrow parallel lines or bands.

Strobila, the asexual colony of the Scyphozoa produced by the Scyphistoma.

Strobilus, an inflorescence made up of imbricated scales, conelike.

Sublingual, pertaining to the region beneath the tongue.

Substratum, that which underlies or supports something.

Surface tension, the tendency of a surface to occupy the least amount of space, thereby exerting a pull greater than that of the substance beneath the surface.

Suspension, the state of a mixture when particles are suspended in a substance although of different density from the substratum.

Suspensoid, a colloid capable of gelation.

Suture, *Bot.* The line of dehiscence; the seam formed by the union of two adjacent margins.

Zool. A seam, or line of union along an immovable articulation as between bones of the skull.

Symbiosis, the living together of two species either for mutual benefit or for the benefit of one without harm to the other.

Symmetry, correspondence or similarity of parts on opposite sides of an axis.

Sympathetic, that portion of the autonomic nervous system in vertebrates which secretes adrenalin; opposed to parasympathetic.

Synapsis, the union of two homologous chromosomes during the growth stages of the maturation process.

Syncytium, a multinucleate mass of protoplasm.

Syndactyl, lateral fusion of fingers or toes.

Synergids, the two nuclei at the upper end of the embryo sac of seed plants which with the egg nucleus constitute the egg apparatus.

Syngamy, the union of two gametes to form a zygote.

Synthesis, any constructive process where simple compounds are built into more complex ones.

System, in animals a system is a group of organs united for the performance of a common function.

Systemic, pertaining to the systems: usually applied to the entire body.

Tanning, the conversion of skin into leather.

Tap root, the primary root which is a direct continuation of the radicle.

Tapetal layer, a membrane of granular cells containing chloroplasts and surrounding sporogenous tissue.

Tarsus, the last segment of the leg of the grasshopper.

Taxonomy, a branch of biology dealing with the classification of animals and plants.

Tegmen, the inner seed coat in angiosperms.

Teloblast, a cell at the posterior end of a trochophore larva from which the mesoderm develops.

Temporal, pertaining to the temporal bone on the side of the skull behind the orbit: the temple.

Tendril, the slender, spirally coiling organ of climbing plants by which the plant attaches itself to a surface.

Tergite, the dorsal division of the cuticle in each segment of the grasshopper.

Terrestrial, living on land: air breathing.

Testa, the outer seed coat in angiosperms.

Testis, the male gonad containing the male germ cells.

Tetrad, two chromosomes united by synapsis and destined to divide, thus representing four ultimate units.

Thallus, a simple, vegetative plant body without differentiation into root, stem, and leaves.

Thermolabile, unstable on heating; said of vitamins that boil out of vegetables.

Thermostabile, stable on heating.

Thermotropism, the reaction of an organism to a stimulus of heat.

Thigmotropism, the reaction of an organism to touch.

Thyroxin, the substance extracted from the thyroid gland which has the properties of thyroid secretions.

Tissue, a group of similar cells performing a similar function.

Toxin, an alkaloid occurring as a by-product of bacterial activity and having poisonous properties.

Toxoid, a toxin that has lost its toxicity but retained its antigenicity.

Tracheal tubes, *Bot.* Tubes formed by the fusion of wood cells and used to conduct water.

Zool. Tubes used for the passage of air through an organism.

Tracheate, an organism breathing from the air; an air breathing arthropod.

Tracheid, an elongated cell in the woody tissue of plants used to conduct water.

Translocation, *Bot.* The transfer of food materials in solution through the sieve tubes of the phloëm of vascular plants.

Genetics: Attachment of a fragment of one chromosome to a nonhomologous chromosome resulting in a new arrangement of genes.

Transmutation, the power of genes to change their position, as in translocation.

Transpiration, the exhalation of watery vapor from the stomata of plants, the water having been raised from the roots in a continuous column.

Trichocyst, one of the minute rodlike bodies in the ectoplasm of certain ciliates, capable of extrusion.

Tropism, a predictable reponse to a stimulus.

Trypsin, an enzyme in the pancreatic juice which converts proteins to peptones in an alkaline medium.

Tuber, a short fleshy underground branch with buds or ''eyes'' in their axils, as the potato.

Turgor, the distention of plant cells and tissues by virtue of the pressure exerted by the water in the cells.

Typhlosole, an inward growth of tissue from the intestine of the earthworm which increases the absorptive surface.

Ultramicroscope, a microscope equipped with a dark-field condenser through which the rays of light enter at the side, making visible against a dark field particles invisible in bright light.

Umbrella, the curved body of a medusa.

Unicellular, composed of one cell.

Uniramous, having only one branch.

Uranium, the radioactive substance from which disintegrating radium atoms discharge radiations into the air, gradually changing the uranium to an inert substance supposed to be lead.

Ureter, the duct which carries the urine from the kidney to the bladder in the higher vertebrates. A metanephric duct.

Vacuole, a spherical cavity in the cytoplasm of a cell, usually containing liquids which enter through a delicate plasma membrane.

Variation, the occurrence of differences between individuals of a species.

Vascular, pertaining to tissues composed of vessels or ducts as the blood vessels, or the vascular bundles.

Vascular bundle, a strand of specialized tissue running through a plant and containing the tissues used for food and water conduction.

Vein, a blood vessel carrying blood to the heart.

Velum, a veil or curtain. Applied to the membranous shelf within the margin of a medusa.

Venter, the expanded basal portion of an archegonium in which the egg cell is formed.

Ventral, the morphologic front of an animal: opposed to dorsal.

Vertex, the crown or dorsal region of the epicranium of the grasshopper and allied insects.

Villi, *Bot.* Fine hairs, forming pubescence on plants.

Zool. Fingerlike processes on the lining of the small intestine which function in the absorption of food.

Virus protein, a protein molecule of exceptional size which has some of the properties of genes. On the borderline betwen the living and the nonliving.

Viscosity, quality of resistance offered by a fluid to the movement of its particles.

Vitality, a state or quality of animation in living organisms.

Vitamin, a chemical substance essential to the proper functioning of metabolic activities.

Vitreous, of, pertaining to, or derived from glass. Applied to the semi-gelatinous, transparent mass which fills the center of the eyeball behind the lens.

Warm blooded, a condition in which an organism retains a fairly constant temperature regardless of fluctuations in the external environment.

Whorl, the arrangement of organs in a circle about an axis, as in flowers.

Wolffian duct, the duct of the mesonephric kidneys in vertebrates which becomes the vas deferens of the male in higher forms.

Wood, lignified tissue in the xylem of the vascular bundles.

Xanthophyll, a yellow pigment in the leaves of plants.

Xerophyte, a plant adapted to life in arid regions.

Xerophthalmia, a disease of the eyes characterized by reddening of the lids, due to the absence of vitamin A from the diet.

Xylem, the woody tissues of the vascular bundles which contain tracheids for the conduction of water.

Yeast, a minute, one-celled fungus producing alcoholic fermentation.

Zoogeography, a science dealing with the distribution and migrations of animals.

Zoology, a branch of biology dealing with animal life.

Zoospore, an asexual swimming spore in the lower plants.

Zymase, an enzyme in yeast cells capable of converting sugar into alcohol and carbon dioxide.

Zymogen, an enzyme as secreted from a gland in an inactive state.

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